IMPACT OF HAMILTON HARBOUR ON WESTERN LAKE ONTARIO

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J. BISHOP, Director
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IMPACT OF HAMILTON HARBOUR

ON

WESTERN LAKE ONTARIO

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FOREWORD

This report represents the results of a number of studies conducted by the Great Lakes Section in 1982 and 1983. In addition, information acquired from the Drinking Water Section of the Water Resources Branch, the Regional Municipality of Halton, the Regional Municipality of Hamilton-Wentworth and the National Water Research Institute of Environment Canada has been included.

The conclusions of this report were presented to the stakeholders and general public in Hamilton in July 1986, as part of the Hamilton Harbour public involvement program for the development of a Remedial Action Plan. In addition, a paper based largely on information contained in this report was presented at the May 1986 International Association for Great Lakes Research (IAGLR) Conference.

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Additional information on drinking water was provided by the Drinking Water Section, Water Resources Branch, as well as the Regional Municipalities of Halton and Hamilton-Wentworth.

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1.0 SUMMARY AND CONCLUSIONS

Hamilton Harbour has long been recognized as an area impacted by industrial and municipal pollutant loadings. The harbour has been identified to the International Joint Commission as an Area of Concern, owing to failure to meet Provincial Water Quality Objectives and guidelines for contaminants in surface water and sediments. Only periodic data had previously been collected on the influence of the harbour on Western Lake Ontario; furthermore, concern has existed about the possibility of impingement of the harbour plume on the Hamilton and Burlington water treatment plant intakes. In order to better define the extent of these problems, the Great Lakes Section of the Ontario Ministry of the Environment conducted an intensive study of the western end of Lake Ontario in 1982 and 1983.

The specific objectives of the study included delineation of the effluent plume flowing from Hamilton Harbour into Western Lake Ontario and intercorrelation of data on wind, currents and plume configuration within 5 km of the Burlington Ship Canal; determination of any actual or potential impacts of the Hamilton Harbour plume on the Hamilton and Burlington municipal water intakes; and evaluation of benthic community structure in the lake sediments adjacent to the outlet of Hamilton Harbour (Burlington Ship Canal) as a refection of the degree of environmental impact on the nearshore area of Lake Ontario. The major conclusions of the study are summarized below.

1. The long-term water movement in Western Lake Ontario was observed to be counterclockwise; however, short periods of clockwise flow (< 1 day) also prevailed. Current speeds are lower than those generally observed in nearshore areas of the Great Lakes, with currents below 5 cm/s occurring 58% of the time. The lowest current speeds occurred at a location immediately north of the Burlington Ship Canal.

2. Two events of lake upwelling and downwelling between July and October in the nearshore region are indicated by thermal records. As these events produce complete exchange of inshore and offshore water, they provide additional dilution to disperse harbour water entering Lake Ontario through the canal.

3. Dilution of surface waters in Western Lake Ontario is generally better than in other nearshore areas of Lake Ontario. However, the better dilution is not attributed to characteristic lake dynamics, but to dissipation of turbulent energy of the water mass exchange through the Burlington Ship Canal.

4. For most of the year, currents in the Burlington Ship Canal exhibit unidirectional (plug) flow at all depths, alternating between flows towards the lake and towards the harbour with periodicities largely controlled by lake oscillations. During the summer (August), stratified flow is observed, with harbour water flowing to the lake at the surface and colder lake water flowing towards the harbour near the bottom. Stratified flow was also observed on one occasion in October.

5. During summer (August) when the harbour is stratified, water chemistry data (nutrients, water clarity, heavy metals) show higher concentrations for parameters such as ammonia, total Kjeldahl nitrogen, total phosphorus, chloride, turbidity, suspended solids, iron and manganese in outflowing waters of the canal, compared to a central harbour sampling location. This suggests the possibility of more direct outflow of industrial and municipal effluents from the southeastern part of the harbour to the canal, without the usual harbour residence period. This condition did not occur in October.

6. Loadings of nutrients and suspended solids from Hamilton Harbour to Lake Ontario were estimated for each canal flow layer and both flow directions. Net loads (10^3t/yr) were as follows: ammonia-N, 1.6; total N, 4.2; total P, 0.07; chloride, 51; suspended solids, 3.6; iron, 0.074; zinc, 0.09. These were similar to or slightly lower than those calculated in 1979, and in all cases were considerably smaller than loadings from the Niagara River to Lake Ontario.

7. Plumes of harbour water in Western Lake Ontario (defined by conductivity or chlorophyll values 10% or more above background) vary widely in shape and orientation from one day to another, and even within the same day. Plume conditions were found on August 24 as far as 4.3 km directly offshore from the Burlington Ship Canal; on October 23 the plume followed the shore southeastward to the vicinity of the Hamilton Water Treatment Plant intake. Such variations in plume shape and orientation can be correlated to measured Lake Ontario current patterns.

8. In nearly all cases, elevated water chemistry values associated with the plume are confined to the surface and up to 3 m depths. Only on one occasion was evidence of a sinking plume (3-6 m depth) observed.

9. Ammonia was found to be a very sensitive indicator of plume conditions, with elevated concentrations being found on several occasions at points farthest from the Burlington Ship Canal. Ammonia results on August 24 suggested a potential for impingement on both the Hamilton and Burlington water intakes. Other nutrients (total Kjeldahl nitrogen, nitrite + nitrate nitrogen and total phosphorus) were also good plume indicators, but water clarity parameters (turbidity and suspended solids) were not, as they were strongly influenced by runoff and sediment resuspension.

10. Copper concentrations exceeded the Provincial Water Quality Objective of 5 ug/L in 26% of the lake samples. Other heavy metals rarely exceeded objective values.

11. In the sediments, most heavy metals exhibit concentrations which increase with increasing depth away from the Burlington Ship Canal. Only a minor influence of Hamilton Harbour is evident for Cr, Cu, Ni, Pb and Zn in the form of elevated concentrations at locations directly offshore from the Burlington Ship Canal.

12. Sequential extractive data indicate that the residual (unavailable) fraction is predominant for most metals. This is in contrast to sediments within the harbour itself, where the Fe/Mn oxide and organic fractions are relatively more important for many metals. This means that heavy metals in the lake sediments are relatively less toxic than those in the harbour sediments.

13. Levels of iron and chromium in the sediment samples exceed the Ministry of the Environment Dredge Spoil Disposal Guidelines (1976) throughout the study area; levels of the other metals exceed the guidelines in deeper areas and directly offshore from the Burlington Ship Canal.

14. The benthic macroinvertebrate community includes a range of species varying from those typical of oligotrophic conditions to pollution-tolerant organisms.

15. Diversity indices for benthic organisms suggest that the area up to 7 km from the canal is moderately polluted. The highest mean diversity indices (> 2.5) found along the northwest shore pertained to an increase in the diversity of facultative benthos.

16. Estimates of relative loadings of polyaromatic hydrocarbons (PAHs) to Western Lake Ontario suggest that the atmosphere is the major source of PAHs, and Hamilton Harbour is a minor source, contributing up to about 30% of the PAHs found in Western Lake Ontario sediments. The distribution of PAHs in the sediments suggests that an unknown source may be contributing PAHs to the northern part of the study area.

17. The PAHs are associated with the clay size fraction of the sediments, suggesting they are highly transportable.

18. Although average water chemistry data at the Hamilton and Burlington Water Treatment Plant (WTP) intakes are not significantly different from those measured at lake background locations, occasional high results were found at the intakes for nutrients (N and P), heavy metals and turbidity. Burlington WTP results assessed in conjunction with plume survey data suggest impingement of the harbour plume on one survey date, while for another date, plume data suggest impingement at the Hamilton WTP intake (no intake data available). Increases of turbidity and associated heavy metals occasionally observed after rainfall are most likely due to runoff and storm-induced sediment resuspension, and are not likely attributable to the harbour discharge.

19. Several organic compounds such as trihalomethanes, phthalates and α-BHC are frequently found in raw and finished drinking water. These compounds generally originate from chlorination or contact with plastic pipes, or in the case of α -BHC, are generally present lakewide. They do not specifically suggest plume impingement.

20. Average organic nitrogen concentrations (0.37 mg/L at the Hamilton WTP and 0.49 mg/L at the Burlington WTP) are in excess of the Ministry's Drinking Water Objectives of 0.15 mg/L. Other parameters measured at the two intakes did not exceed the Drinking Water Objectives.

1.1 RECOMMENDATIONS

1. Correlation of plume parameter concentrations with WTP intake data requires additional monitoring and investigation to provide statistically valid conclusions. A wider range of contaminants analyzed at parts per trillion detection limits for specific, industry-related compounds in Lake Ontario, and concurrent plume tracking, may provide clearer indications of potential impacts on WTP intakes.

2. In order to be able to better define the extent of a plume in field conditions, improved technology should be developed for plume- tracking studies in nearshore lake conditions. Recent developments with ammonia electrodes are especially relevant as this compound was shown to be a sensitive indicator of the harbour plume. Plume tracking and position-fixing data should be directly transcribed using an on-board computer to improve data processing.

3. In order to better predict the dispersion of a plume such as that from Hamilton Harbour, further development of models to predict fate and transport of hazardous contaminants in water is necessary. This should include volatization, degradation, dilution, sedimentation and sediment resuspension, water column/sediment exchange, etc. Such modelling should include biological components such as phytoplankton, zooplankton, bottom fauna, fish, etc.

4. Contaminant analysis of sediments and invertebrates should be conducted to determine the availability of heavy metals and organic contaminants to the biological community. This should include particle size fractionation of the sediments and chemical analysis of specific fractions (clay, etc.), as well as the extent of invertebrate bioconcentration of contaminants, which may function as a biological mechanism for uptake by higher trophic levels.

5. Additional current meters should be deployed at locations closer to the ship canal where navigation permits. These will provide additional input to any fate model, and will verify the existence of lower current speeds close to shore. Current meters located near the bottom will also provide useful input for sediment resuspension models.

6. In view of the high metal concentration in a bottom sediment core located outside the Burlington Ship Canal, studies should be carried out to establish the source of these materials. These studies should include size fractionation and mineralogical analyses of the cores.

2.0 COASTAL DYNAMICS OF WESTERN LAKE ONTARIO NEARSHORE

2.1 INTRODUCTION

The water quality of the nearshore regions of Western Lake Ontario is influenced by the Lake Ontario-Hamilton Harbour water exchange, circulation patterns in the area and the dispersal properties of the water movements. Therefore, an understanding of the dynamics of this coastal region is considered necessary for the effective management of nearshore water and that of Hamilton Harbour.

This study was initiated by the Ontario Ministry of the Environment (MOE) to document the dynamics of Western Lake Ontario and to assess actual or potential impacts on beneficial water uses in the area (two water intakes and three recreational beaches). This work was designed to complement concurrent water quality and plume tracking studies described in Sections 3 and 4.

2.2 STUDY AREA

The study area extends from east of the Burlington Water Treatment Plant (WTP) intake in the north to east of the Hamilton WTP intake in the south, encompassing the western end of Lake Ontario (see Figure 2.1). In addition to the aforementioned major water intakes, the study area includes recreational beaches (Hamilton, Burlington and Van Wagners) which may be subjected to the flow of harbour water to the lake through the Burlington Canal.

The shore of the study area is regular and represents a large nearshore embayment. The bottom topography is characterized by a smooth floor with a slope of 80:1 up to a depth of 5 m. Thereafter the slope drops off to 100:1 up to a depth of 10 m and 125:1 up to 20 m depth.

2.3 SURVEY DESIGN

The survey was designed to study the coastal climatology of the area, relative to the two major water intakes and the behaviour of the harbour water plume as it mixes with the lake water. Locations 1120 and 1121 (see Figure 2.1) were selected on either side of the Burlington Canal to assess the trajectory of the harbour plume. Sites 1122 and 1123 (see Figure 2.1) were located near the two water intakes to determine any impact on the water quality in the vicinity of the intakes, as well as to provide input to estimate the general circulation patterns of the bay. All self-recording current instruments were operated in 3 - 6 m from water surface (see Table 2.1) as this layer is considered to be representative of the harbour plume from Burlington Canal. The water movement data were collected in the study area by Aanderra RCM4 current instruments, set to record every 15 or 30 minutes. Four instruments were operated from 12 May 1982 to 29 April 1983 to measure and record current speed and direction and water temperature.

2.4 DATA ANALYSIS

In order to eliminate the short period fluctuations of the measurements, all data were pre-whitened (Blackman and Tukey, 1959) using binomial coefficients (Panofsky and Briar 1968). The data are presented in the form of time series and stick vectors, rose histograms, selected successive vector plots and tables of frequency of occurrence and current speed and direction (see Appendix). The complete series of data plots are presented in an Appendix which is available on request from the Great Lakes Section, Water Resources Branch.

Spectral analyses were performed on the hourly average values of the resolved current speeds to identify the physical processes responsible for the water movements in the study area (see Table 2.2).

Successive vectors of the current data during the periods of plume survey were computer plotted (available on request). These figures show the trajectory of a particle, if released at the current meter location.

2.5 RESULTS AND DISCUSSIONS

2.5.1 Spectral Analysis

Time series of current data were subjected to spectral analysis to compute the significant energy peaks or periods of oscillations. These were then compared to the theoretically calculated oscillations of the lake. A good comparison between the observed and theoretical oscillation periods validates the collected data and identifies the physical mechanisms responsible for the motions in the study area.

Spectral analysis (Table 2.2) of the current speed time series indicated the presence of statistically significant energy peaks.

The 24 h period observed was obviously due to diurnal effects while the 12 h period observed was due to the presence of tidal motions. These effects, however, were not evident in most data sets. The 17.1 h periods were observed more frequently and these are the periods of inertial oscillations, i.e., a balance between local particle acceleration and the Coriolis force. High frequency oscillations (3 to 10 h) were also observed (Table 2.2) and these correspond to the internal waves, seiches and turbulance. Specifically, the 5.7 to 6.0 h period corresponds to the Merian mode (Rockwell 1966), the 5.2 h period is the universal period of longitudinal surface oscillations (Simpson and Anderson 1964) and the 4.8 h period is the first mode of longitudinal free oscillations (Rockwell 1966). The observed periods of <4h may be attributed to nearshore geometry. Most observed periods can be explained and therefore, the data collected is considered valid.

2.5.2 Thermal Structure

Knowledge of the thermal regime in the study area is considered essential to an understanding of certain physical processes, such as upwelling and downwelling episodes and their impact on the water quality.

The mean temperature (measured by current meters) varied from 1.6°C to 18.9°C (see Table 2.3) and the corresponding standard deviations ranged from 0.3°C to 3.9°C. As expected, the maximum mean temperatures occurred during the first two weeks of August and minimum mean during February at all locations. Site 1122, near the Burlington WTP intake, exhibited cooler water from May to November as compared to other study locations. The instrument and data translations at this location were checked and no discrepancies were observed. However, the reasons for cooler water at this location were not evident.

Vertical temperature profiles were not measured during the study period and it is therefore not possible to discuss the presence or position of the thermocline. However, the thermocline is generally present in Lake Ontario coastal water from about mid-July to mid-September. This stratification often results in opposite flow in the two layers divided by the thermocline.

A close examination of the temperature time series plots (Appendix Figures 2.01 to 2.48) indicates one event of downwelling by the end of July (4-6 days) and one of upwelling on 19 October (3-5 days). Upwelling and downwelling events (see Table 2.4) are generally associated with complete exchange of inshore and offshore water (Csanady 1972), resulting in improved water quality in the nearshore areas.

2.5.3 Nearshore Currents

Knowledge of nearshore currents is considered important to predict the transport and dispersion of any waste discharge and its impact on other water users in the region. Figures 2.1 and 2.2 show the net resultant vectors for the monthly records at all locations. It is apparent that currents are very slow at the extreme end locations, (1120 and 1121: see Figure 2.1), but increase in speed at the south-eastern location (1123). The current speed at the surface may be at least twice the measured values at 3 to 6 m below the surface (Palmer 1984) and the directional differences can be up to 30°. The overall circulation in the study area may be considered counterclockwise for the period of May 1982 to April 1983 (see Figure 2.2). This is consistent with the

shoreline configuration and the presence of large counterclockwise gyres in the western end of Lake Ontario (Pickett and Dessett, 1979).

Statistical summaries of the current results are presented in Tables 2.5 to 2.8. The mean speed varied from 2.5 to 12.8 cm/s while the maximum speed recorded during the study was 48 cm/s. Relatively faster currents were observed in the winter. Coastal jetting speeds (>20 cm/s) occurred for less than 1% of the time and are, therefore, considered insignificant episodes. Stagnant currents (<5 cm/s) were observed for 58% of the overall time (see Table 2.9), a maximum of 78% of the time at site 1120 and a minimum of 28% of the time at mooring 1123. Locations 1121 and 1122 exhibited similar stagnant periods of 62 to 63% of the time. The virtual absence of coastal jetting (<1% of the time) and long periods of stagnation (up to 3 weeks) were observed in the study area. The length of stagnation episodes were relatively shorter during the winter months and ranged from 1/2 to 12 days, most episodes being less than 5 days. This is contrary to results from other coastal zones of Great Lakes (Kohli 1982), where stagnation periods during summer are generally less than a day and coastal jettings continued for up to a week (Kohli 1982). This anomaly may be attributed to the shoreline geometry of the study area, i.e., the extreme narrow end of the elliptical lake. Since the circulation is generally counterclockwise, from east to west on the northern shores (Kohli 1982), flow approaching the western end of the lake must slow down, before turning south and then east along the southern shores. Such a reduction in speed may be responsible for the observed current episodes, i.e. long periods of stagnation (58% - see Table 2.9), short periods of coastal jetting (<1%) and moderate currents of 5-20 cm/s for 42% of time.

2.5.4 Plume Tracking

Plume trackings in the study area were conducted from May to October 1982 on several occasions to assess the impact of Burlington Canal on the western end of Lake Ontario. The details of the tracking periods and methodology are described in Section 4. Chlorophyll and conductivity were chosen as conservative tracers for the study. The results of the plume trackings are illustrated by contour plottings

(see Figures 2.4-2.17), the mean current speed and the circulation pattern during the plume trackings are shown on each plot.

Figures 2.4-2.17 illustrate the extent (1-5 km) of water quality (conductivity and chlorophyll) plume from Burlington Canal. However, Kohli (1984) estimated the extent of travel of water parcel from Burlington Canal as 0.5 to 1.5 km, which is entirely due to the momentum of water leaving the canal. The water quality plume as measured by the present study is 2-3 times larger than the extent of water parcel from the canal. The water quality plume from the canal disperses due to its momentum from the canal (as estimated by Kohli 1984) and lake dynamics. Its extent depends on the conductivity levels in the canal and lake background.

Good agreement between the plume development and water circulation patterns is apparent from figures 2.4 to 2.17. The water quality surveys were carried out on 6 days (June 29, 30; August 24, 26; October 22, 23). Of the survey days, current circulations exhibited clockwise movements for three days, counterclockwise movements for two days and eddy type movements on one day (June 30).

On June 30, the currents exhibited two large eddies (1-2 km); counterclockwise eddy to the north of the canal and clockwise eddy to the south of the canal. Such large-scale eddies are not beneficial for dispersion of waste materials since the materials discharged can return to the starting point after travelling around the path of the eddy. If this process persists, it can cause build-up of pollutants in the area of discharge. However, these large eddies usually breakup in a day or two. The presence of small-scale eddies (50 - 100 m) help disperse the waste plume by entraining fresh, cleaner water by 'tearing' the plume.

The two eddies produced dips in the contours (see Figure 2.8) and the offshore currents appear to be taking the chlorophyll plume to the east (see the dashed contours of Figure 2.9). On 26 August, the flow was generally counterclockwise (as with the long-term circulation) and the currents were moderate with a mean speed of 6.4 cm/s. The conductivity and chlorophyll plumes are well developed, but do not show any effects of the circulation pattern. This may be attributed to the momentum of

the flow from the Burlington Canal in a relatively calm lake environment. On 23 October, the currents were calm with a mean speed of 1.6 cm/s. The direction associated with such small currents is generally meaningless. However, the conductivity plume from the Burlington Canal shows the circulation to be counterclockwise with the plume approaching (see Figure 2.16) the Hamilton WTP intake on October 23.

Since the water column during October is isothermal, the water movement at surface and lake bottom may be moving in phase. The impact of surface plume from the Burlington Canal to the Hamilton WTP intake, therefore, reflects a similar impact at the intake level. The plume from the Burlington Canal reached the Hamilton WTP intake on one occasion (October 23) during the present study. However, no such impact of the Burlington Canal on the Burlington WTP intake was observed.

The dilution due to surface spreading is usually small (Kohli 1981) and is computed as follows:

$$D_x = (Co - C_B)/(C_x - C_B)$$

where D_x = the dilution ratio at distance x from the source (midpoint of eastern end of Burlington Canal)

C_o = the concentration at source

C_x = the concentration at distance x from the source.

C_B = the background or lake ambient concentration.

The results of plume characteristics are presented in Table 2.10.

It is apparent that the dilution ratios for the two tracers used are different. The conductivity data show better dilution ratios than the chlorophyll data at the same distance and time. This may be attributed to the increase of chlorophyll levels in the lake due to photosynthesis during daylight, resulting in the lower apparent dilution of the harbour chlorophyll. Thus, the dilution ratios computed for conductivity are considered more representative estimates and are generally better than those for other coastal regions. Kohli (1984) estimated surface dilution ratios of 1.5 at 1000 m in the Ashbridges Bay area of the Eastern Toronto Waterfront, Lake Ontario, while those for the present study range from 2.1 at 700 m to 9.0 at 1250 m.

Kohli (1979) recorded in Burlington Canal (see Figure 2.1) an average current speed of 11.5 cm/s and a maximum speed of 45 cm/s. The dimensionless Reynolds Number (Re) is defined as:

$$Re = \frac{UL}{\nu}$$

where U = Velocity

L = length scale

ν = Kinematic viscosity

Kohli (1979) showed that Re was of the order of 10^5 to 10^6 and therefore fully developed turbulent flow prevailed in the canal. The dissipation of this turbulent energy in the immediate vicinity of the lake would result in better surface dilution.

2.6 CONCLUSIONS

The long-term water movement in Western Lake Ontario was observed to be counterclockwise, in agreement with the long-term circulation of Lake Ontario. However, short-term (<1 day) circulation in the clockwise direction was detected for three out of 5 plume tracking days. Large-scale eddies were present on one occasion, but these do not provide any benefit to the dispersion processes which usually rely on small scale turbulence.

The current speeds were generally slow on either side of the Burlington Canal and relatively faster at the outer locations. The mean monthly current speed in the study area varied from 2.5 to 12.8 cm/s while the maximum speed recorded was 48 cm/s. Winter currents were relatively faster than summer ones; the counterclockwise circulation of summer months did not change during the winter period, possibly due to the local shore configuration. Coastal jetting speeds (|20 cm/s) occurred for less than 1% of the time while stagnant currents (<5 cm/s) were observed for 58% of the time. Thus, stagnant conditions prevailed in the region for most of the time. Consequently, advective transport in this area would be much smaller than that observed in other coastal regions.

The plume trackings showed better surface dilution processes compared to other coastal regions. However, the better dilution is not attributed to lake dynamics, but to the dissipation of the turbulent energy of the Burlington Canal discharge. Conductivity and chlorophyll were used as tracers. As chlorophyll levels may increase due to photosynthesis in lake waters during daylight, chlorophyll is not considered to be a reliable tracer.

The surface plume from the Burlington Canal was tracked to the Hamilton WTP intake site on one occasion. This may also impact at the intake level due to the presence of the isothermal conditions in the lake during October. No such impact of the Burlington Canal on the Burlington WTP intake was observed during the present study.

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TABLE 2.1: Current Meter Operations, Western Lake Ontario, 1982

Location Code	Water Depth	Instrument Depth from Bottom	Period of Operation	
	m	m	From	To
1 1 2 0	12.2	9.2	12 May 82	18 Nov 82
			18 Nov 82	14 Apr 83
1 1 2 1	12.2	9.2	12 May 82	29 Nov 82
			1 Dec 82	22 Apr 83
1 1 2 2	14.6	10.4	12 May 82	18 Nov 82
			1 Dec 82	29 Apr 83
1 I 2 3	18.3	12.2	12 May 82	29 Nov 82

TABLE 2.1a

LOCATION CODE : 1120
AREA : BURLINGTON AREA
LAKE : ONTARIO

PERIOD : MAY 82
LATITUDE : 43 18 50 W
LONGITUDE : 79 47 0 N

FREQUENCY TABLE

SPEED(CM/S)	DIRECTION IN DEGREES 337.50-22.49	22.50-67.49	67.50-112.49	112.50-157.49	157.50-202.49	202.50-247.49	247.50-292.49	292.50-337.49	ROW SUMS
1.00 -- 1.99	11.79	5.23	2.03	0.71	2.13	7.62	7.22	10.16	46.90
2.00 -- 2.99	3.86	2.03	0.97	0.91	2.74	2.95	1.47	1.63	16.57
3.00 -- 3.99	3.71	0.61	0.51	0.36	1.42	2.79	1.07	1.63	12.09
4.00 -- 4.99	0.97	0.25	0.25	0.61	2.54	2.34	0.30	0.81	8.08
5.00 -- 5.99	0.0	0.05	0.15	0.97	2.13	1.22	0.0	0.0	4.52
6.00 -- 6.99	0.0	0.0	0.0	0.81	1.37	0.56	0.0	0.0	2.74
7.00 -- 12.99	0.0	0.0	0.46	1.02	7.42	0.20	0.0	0.0	9.10
COLUMN SUMS	20.33	8.18	4.37	5.39	19.77	17.68	10.06	14.23	100.00

RESULTANT CURRENT IS 1.01 CM/S AT 202 DEG FROM NORTH
MEAN CURRENT IS 3.16 CM/S
MAXIMUM CURRENT IS 12.07 CM/S
MINIMUM CURRENT IS 1.50 CM/S

TOTAL NO. READINGS 1968
PERSISTENCE IS 0.32
READINGS TAKEN EVERY 15 MIN

METER OPERATIONS

METER OPERATED AT 9.2 M FROM BOTTOM IN 12.2 M OF WATER

STARTED AT 0.04 HRS. ON 12 TH DAY OF 5 TH MONTH 1982
ENDED AT 23.49 HRS. ON 31 TH DAY OF 5 TH MONTH 1982

Table 2.2: Significant Spectral Periods (h)
Western Lake Ontario, 1982

Location	Month	(80% Confidence Level)	
		Along-shore	Across-shore
1120	May	None	8.6
	Jun	16.3	4.8, 3.8, 3.6*
	Jul	3.3*, 7.1, 4.6, 3.4	20.0, 10.0
	Aug	None	30.0*
	Sep	5.2	None
	Oct	5.7, 3.8*, 3.2	None
	Nov	3.1	30.0, 9.2
1121	May	3.5	3.8
	Jun	None	7.5, 5.7
	Jul	17.1*, 10.9, 10.0, 3.8	17.1*
	Aug	8.0	None
	Sep	20.0, 7.1, 5.7	17.1, 4.4
	Oct	10.0*, 6.3, 4.4, 3.2	17.1*6.7*,5.0* 4.13.6*
	Nov	10.9, 5.0, 4.0, 3.9, 3.1	17.1, 7.1
1122	May	None	10.0, 5.2, 4.3
	Jun	3.2, 2.9	3.2
	Jul	13.3, 12.08.68.0*,6.0*	20.0
	Aug	None	None
	Sep	20.0, 3.5	12.0, 10.9
	Oct	20.0, 17.1,9.2, 5.7,4.4	20.0, 17.1, 8.6
	Nov	9.2	3.0
1123	May	17.1*, 4.8*, 3.6	8.6, 8.0*, 4.8*, 3.4*
	Jun	6.3, 6.0*	4.4, 3.3
	Jul	20.0, 9.2, 8.6	10.9, 8.0, 6.0
	Aug	17.1, 10.0	20.0*, 8.6, 4.3, 4.1*
	Sep	24.0, 6.7	None
	Oct	8.6	None
	Nov	7.5, 3.2	17.1, 7.5, 3.4, 2.9

* 95% Confidence Level

TABLE 2.3: Mean Water Temperature (C), Western Lake Ontario, 1982-83

Location # Period	1 1 2 0	1 1 2 1	1 1 2 2	1 1 2 3
May 82	7.7 (0.9)	7.3 (0.9)	2.8 (1.0)	7.4 (1.2)
June 82	8.8 (1.8)	9.8 (1.3)	5.6 (1.3)	11.2 (1.8)
Jul 82	7.1 (2.7)	8.0 (2.8)	3.6 (2.4)	13.1 (3.1)
Aug (1-11) 82	15.3 (3.9)	16.0 (3.3)	12.2 (3.5)	18.9 (0.8)
Aug (24-31)82	7.5 (1.4)	9.0 (0.5)	4.2 (0.7)	9.4 (0.5)
Sep 82	11.1 (2.8)	11.9 (2.2)	7.6 (2.7)	12.2 (1.7)
Oct 82	11.5 (3.7)	11.8 (3.4)	8.1 (3.5)	12.5 (2.5)
Nov 82	5.8 (0.9)	5.8 (1.6)	1.9 (0.9)	5.8 (1.8)
Dec 82	3.6 (0.9)	3.9 (0.9)	3.9 (0.6)	
Jan 83	2.4 (0.9)	2.3 (0.8)	2.6 (0.8)	
Feb 83	1.5 (0.4)	1.6 (0.4)	1.6 (0.4)	
Mar 83	2.3 (0.3)	2.3 (0.3)	2.3 (0.3)	
Apr 83	3.6 (0.6)	3.8 (0.6)	3.7 (0.6)	

NOTE: Figures in parentheses are monthly standard deviations.

TABLE 2.4: Upwelling and Downwelling Episodes Western Lake Ontario, 1983

Location	Month	Dates	Upwelling/(U) Downwelling(D)	Episode Length (d)
1 1 2 0	July	28-31	D	4
	Oct	19-23	U	5
1 1 2 1	Jul	28-31	D	4
	Oct	19-24	U	6
1 1 2 2	Jul/Aug	29-2	D	5
	Oct	21-23	U	3
1 1 2 3	Jul/Aug	28-2	D	6

TABLE 2.5: Statistical Summary of Current Meter Operations, Western Lake Ontario, 1982-83
Location # 1120

	May	Jun	July	Aug 1-11	Aug 24-31	Sept	Oct	Nov
Resultant direction (0° as North)	202	203	226	204	291	221	189	259
Resultant speed (cm/s)	1.01	1.02	0.48	1.68	1.11	0.90	1.09	1.08
Average speed (cm/s)	3.16	2.75	2.52	3.96	2.67	3.35	3.08	2.95
Maximum speed (cm/s)	12	13	18	14	13	19	19	12
Persistence factor	0.32	0.37	0.19	0.42	0.42	0.27	0.35	0.37
Percentage of time going in direction of resultant	20	16	13	29	20	13	22	35
Total number of readings	1968	2928	3024	994	816	2928	3024	1683
Interval of readings (min)	15	15	15	15	15	15	15	15

TABLE 2.5: Cont'd

	Nov	Dec	Jan.	Feb	Mar	Apr
Resultant direction (0^o as North)	233	292	273	200	190	177
Resultant speed (cm/s)	1.65	0.82	0.62	1.43	3.61	3.46
Average speed (cm/s)	3.47	3.23	3.79	4.49	5.36	5.73
Maximum speed (cm/s)	9	14	16	27	33	25
Persistence factor	0.48	0.25	0.16	0.32	0.67	0.60
Percentage of time going in direction of resultant						
Total number of readings	593	1488	1488	1344	1488	655
Interval of readings (min)	30	30	30	30	30	30

TABLE 2.6: Statistical Summary of Current Meter Operations, Western Lake Ontario, 1982-83
Location # 1121

	May	Jun	July	Aug 1-11	Aug 24-31	Sept	Oct	Nov
Resultant direction (0° as North)	157	17	190	183	254	66	125	193
Resultant speed (cm/s)	2.57	0.15	0.52	0.75	1.28	0.17	1.21	0.88
Average speed (cm/s)	4.13	4.15	3.62	6.52	4.03	5.28	4.65	4.66
Maximum speed (cm/s)	15	13	18	16	11	21	28	13
Persistence factor	0.62	0.04	0.14	0.11	0.32	0.03	0.26	0.19
Percentage of time going in direction of resultant	42	16	16	18	21	5	33	27
Total number of readings	1968	2928	3024	1015	720	2928	3024	2745
Interval of readings (min)	15	15	15	15	15	15	15	15

TABLE 2.6: Cont'd

	Dec	Jan	Feb	Mar.	Apr.
Resultant direction (0^o as North)	156	144	131	134	116
Resultant speed (cm/s)	0.57	1.98	1.79	4.95	2.15
Average speed (cm/s)	4.57	5.26	6.23	7.46	6.22
Maximum speed (cm/s)	25	20	28	48	34
Persistence factor	0.12	0.38	0.29	0.66	0.35
Percentage of time going in direction of resultant					
Total number of readings	1488	1489	1344	1488	1040
Interval of readings (min)	30	30	30	30	30

TABLE 2.7: Statistical Summary of Current Meter Operations, Western Lake Ontario, 1982-83
Location # 1122

	May	Jun	July	Aug 1-11	Aug 24-31	Sept	Oct	Nov
Resultant direction (0^{o} as North)	219	329	351	211	32	29	358	33
Resultant speed (cm/s)	2.71	0.47	0.91	5.08	1.84	1.51	1.31	1.47
Average speed (cm/s)	5.26	4.78	4.12	7.81	5.84	4.37	3.38	4.75
Maximum speed (cm/s)	25	17	26	20	17	30	18	16
Persistence factor	0.51	0.10	0.22	0.65	0.31	0.34	0.39	0.31
Percentage of time going in direction of resultant	35	5	12	50	49	36	35	49
Total number of readings	1968	2928	3024	631	816	2928	3024	1697
Interval of readings (min)	15	15	15	15	15	15	15	15

TABLE 2.7: Cont'd

	Dec	Jan	Feb	Mar	Apr
Resultant direction (0° as North)	27	230	199	213	209
Resultant speed (cm/s)	1.60	.26	1.48	3.70	2.37
Average speed (cm/s)	4.41	4.69	5.98	6.45	5.47
Maximum speed (cm/s)	17	19	21	30	27
Persistence factor	0.36	0.06	0.25	0.57	0.43
Percentage of time going in direction of resultant					
Total number of readings	1488	1488	1344	1488	1376
Interval of readings (min)	30	30	30	30	30

TABLE 2.8: Statistical Summary of Current Meter Operations, Western Lake Ontario, 1982-83
Location # 1123

	May	Jun	July	Aug 1-11	Aug 24-31	Sept	Oct	Nov
Resultant direction (0^{o} as North)	92	127	216	215	92	108	90	103
Resultant speed (cm/s)	7.02	3.25	1.04	0.92	3.22	3.49	3.14	5.02
Average speed (cm/s)	8.36	8.42	7.67	12.75	5.80	7.42	7.88	8.90
Maximum speed (cm/s)	26	23	22	26	18	28	21	20
Persistence factor	0.84	0.39	0.14	0.07	0.56	0.47	0.40	0.56
Percentage of time going in direction of resultant	65	18	13	8	46	38	41	40
Total number of readings	1968	2928	3024	1302	720	2928	3024	2746
Interval of readings (min)	15	15	15	15	15	15	15	15

TABLE 2.9: Percentage of Stagnation Periods, W. Lake Ontario, 1982-83

Period	Location #			
	1 1 2 0	1 1 2 1	1 1 2 2	1 1 2 3
May	83	75	65	37
June	88	71	64	21
Jul	91	78	72	24
Aug	79	58	39	30
Sep	80	59	69	39
Oct	86	68	79	27
Nov	82	60	61	18
Dec	74	65	64	
Jan	79	63	69	
Feb	77	58	53	
Mar	62	44	57	
Apr	60	58	57	
Mean	78	63	62	28

Grand Mean = 58

TABLE 2.10: Typical Plume Characteristics from Burlington Canal to W. Lake Ontario, 1982

Date	Current Speed (cm/s)	Conductivity (umhos/cm)					Cholorophyll (ug/L)				
			x(m)	C_x	Cx/Co	D_x		X(m)	C_x	C_x/Co	Dx
29 June	2.4	Co=487	400	372	0.76	2.5	Co=14.0	1200	12	0.86	1.2
		CB=290	2000	330	0.68	4.9	CB=3.6	2500	9	0.64	1.9
30 June	3.3	Co=558	700	440	0.79	2.1	Co=12.0	1000	10	0.83	1.3
		CB=329	1400	384	0.69	4.2	CB=3.0	2000	7	0.58	2.3
24 August	3.3	Co=520	1000	421	0.81	2.3	Co=24.0	1000	14	0.58	2.0
		CB=345	3000	383	0.74	4.6	CB=4.1	3000	8	0.33	5.0
26 August	6.4	Co=518	600	415	0.80	2.3	Co=24.0	600	13	0.54	2.0
		CB=337	1200	368	0.71	5.8	CB=2.0	1200	8	0.33	3.7
22 October	2.4	Co=503	700	398	0.79	3.0	Co=15.5	500	10	0.65	1.6
		CB=346	1250	363	0.72	9.0	CB=2.8	800	5	0.32	5.8

Note: x is distance from midpoint (0) at eastern end of Burlington Canal in meters
Cx is the concentration at distance x from 0
Co is the concentration at 0
CB is background concentrations
Dx is the dilution

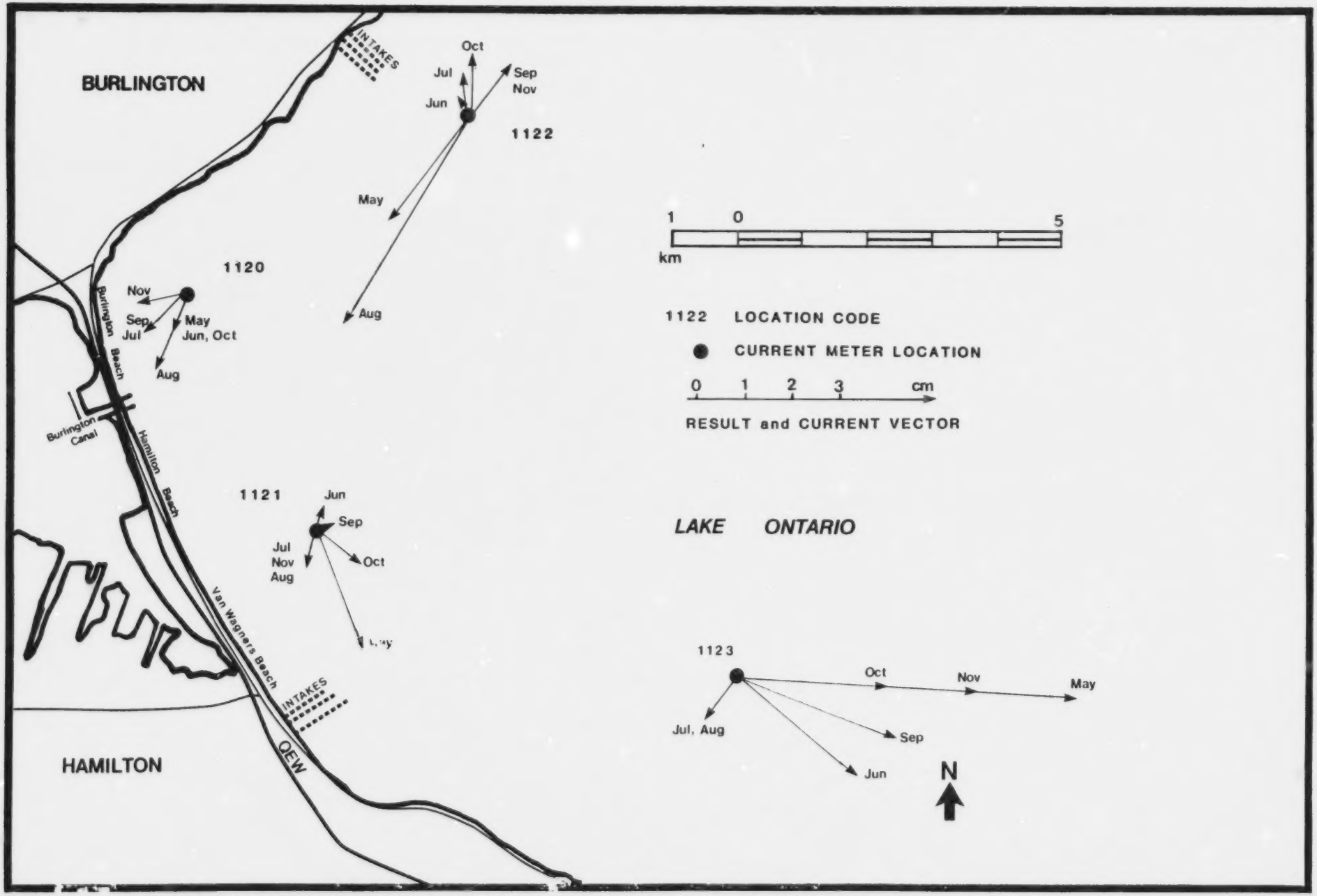

FIG. 2.1: RESULTANT CURRENTS, WESTERN LAKE ONTARIO, JUNE-NOVEMBER 1982

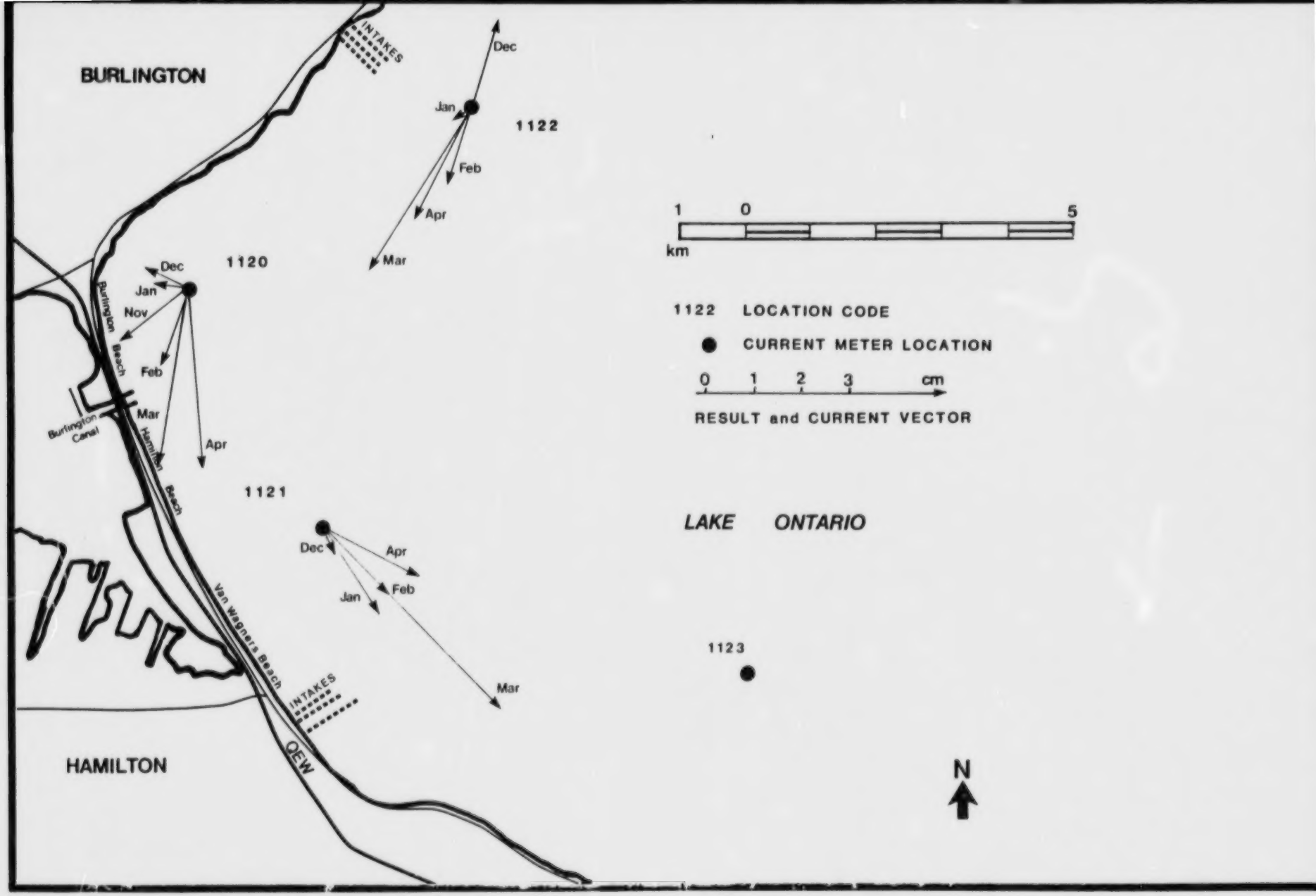

FIG. 2.2: RESULTANT CURRENTS, WESTERN LAKE ONTARIO, DECEMBER 1982–APRIL 1983

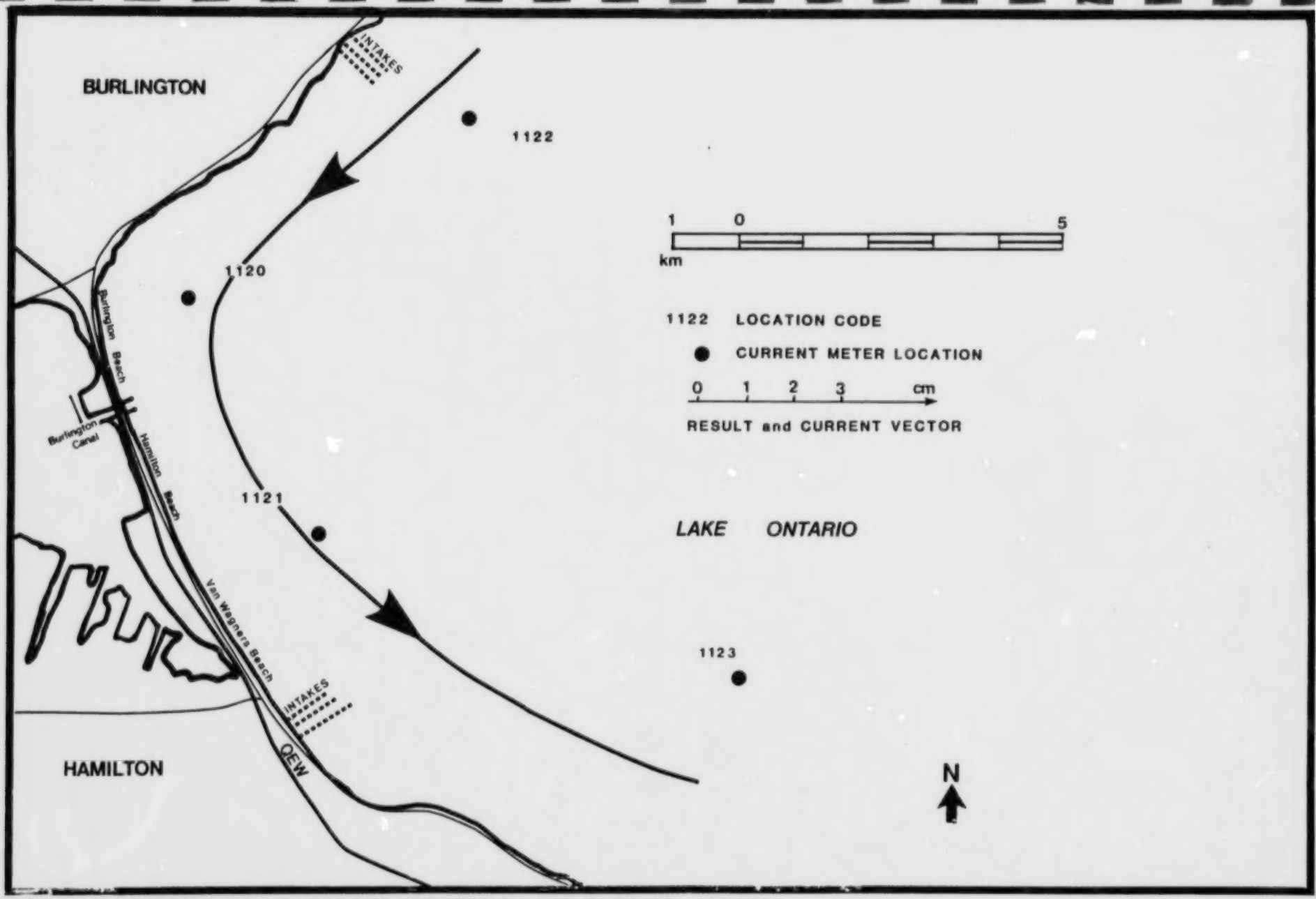

FIG 2.3 : CIRCULATION PATTERNS, WESTERN LAKE ONTARIO, 1982/83

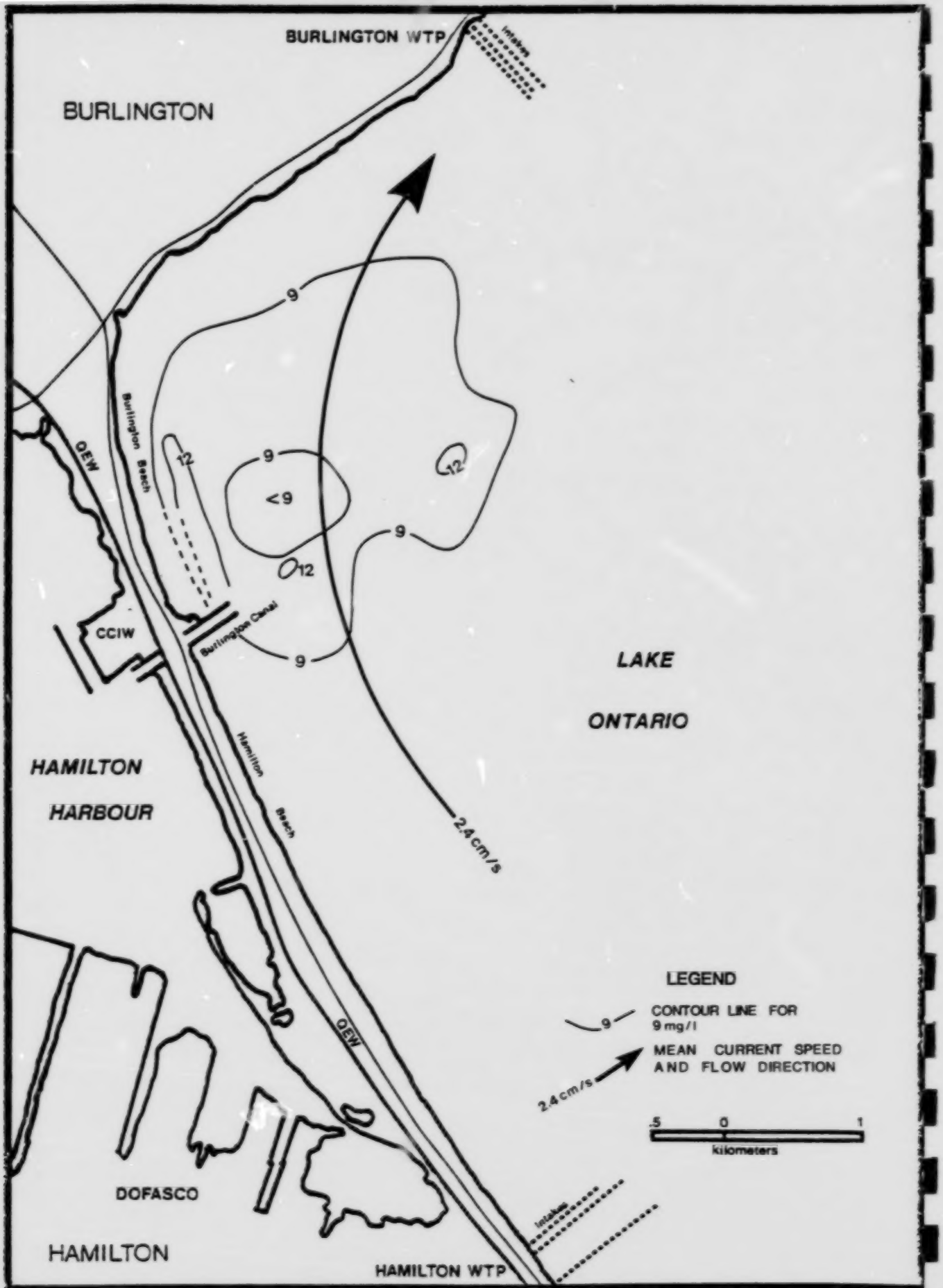

FIG 2.4 : CHLOROPHYLL PLUME CONTOURS, 29 JUNE 1982, WESTERN LAKE ONTARIO

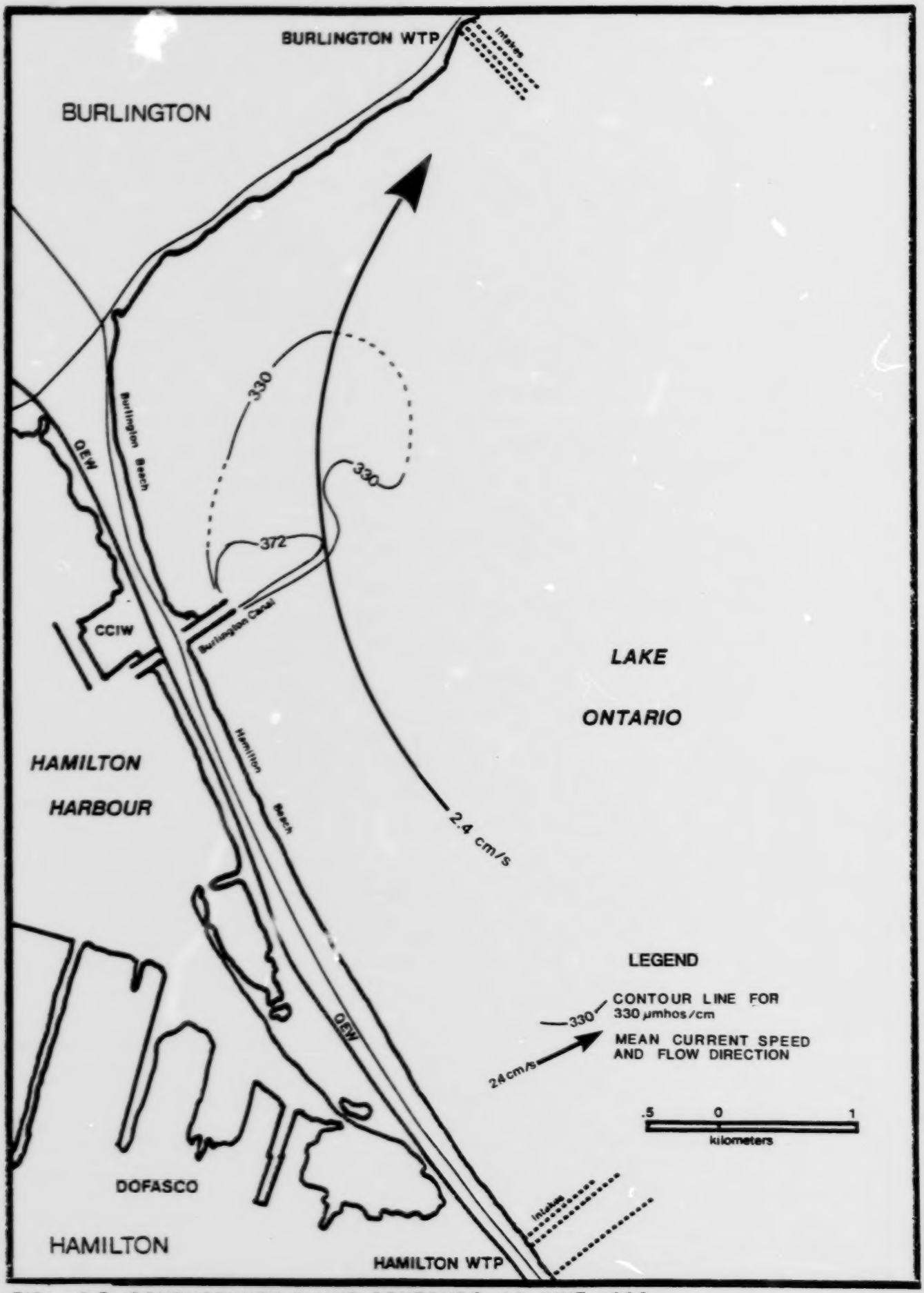

FIG 2.5: CONDUCTIVITY PLUME CONTOURS, 29 JUNE 1982, WESTERN LAKE ONTARIO

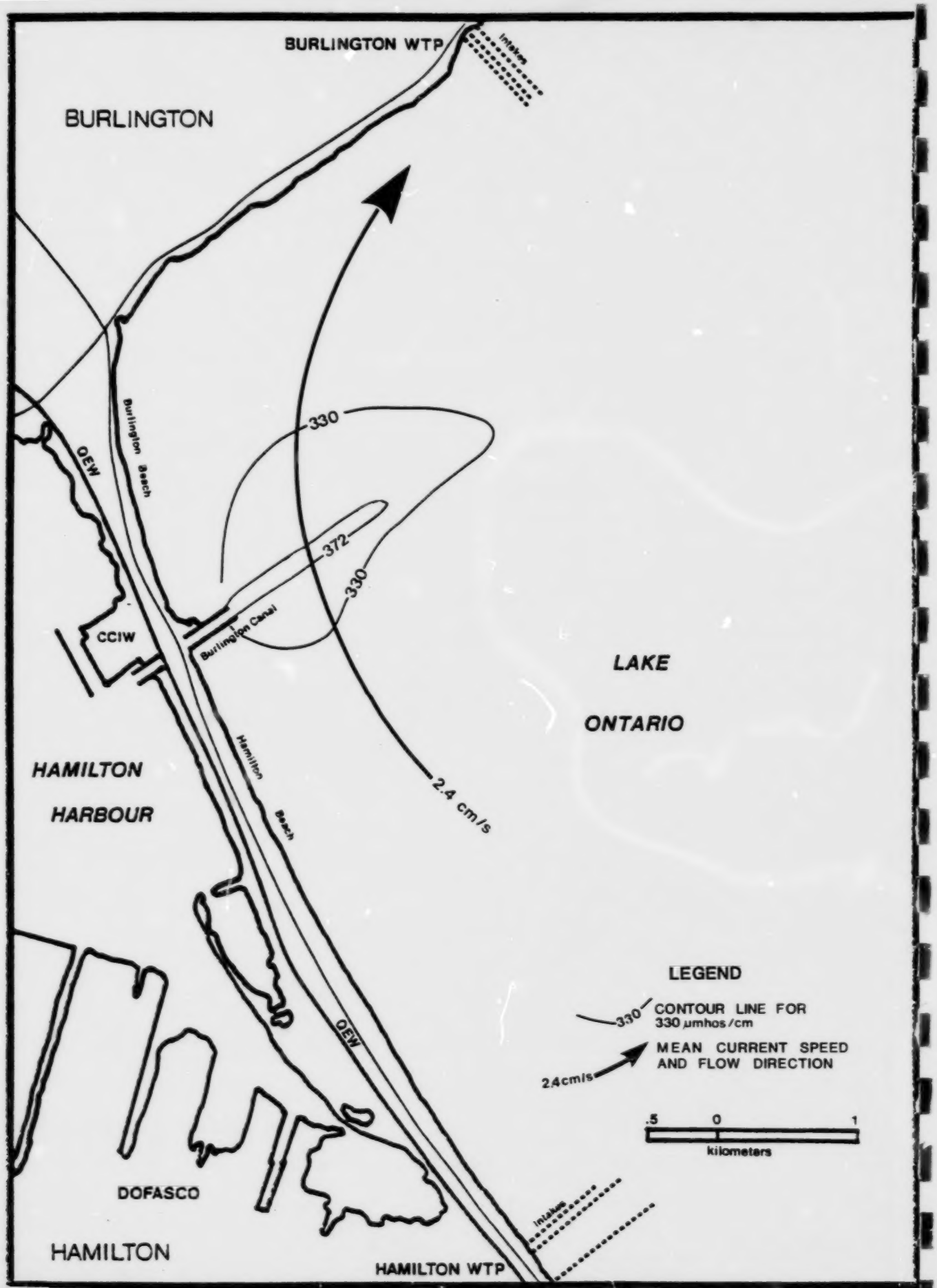

FIG. 2.6 : CONDUCTIVITY PLUME CONTOURS, 29 JUNE 1982, WESTERN LAKE ONTARIO

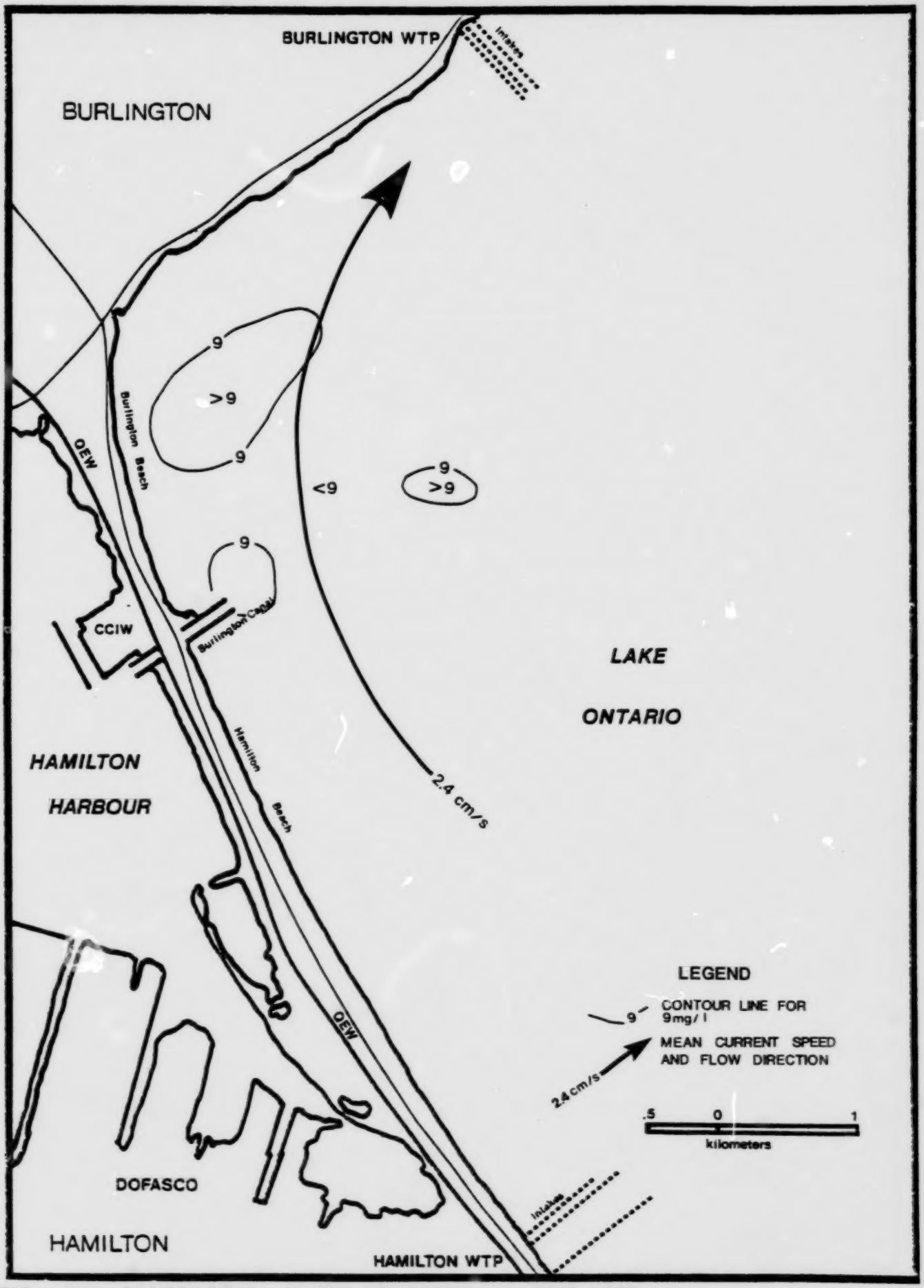

FIG. 2.7 : CHLOROPHYLL PLUME CONTOURS, 29 JUNE 1982, WESTERN LAKE ONTARIO

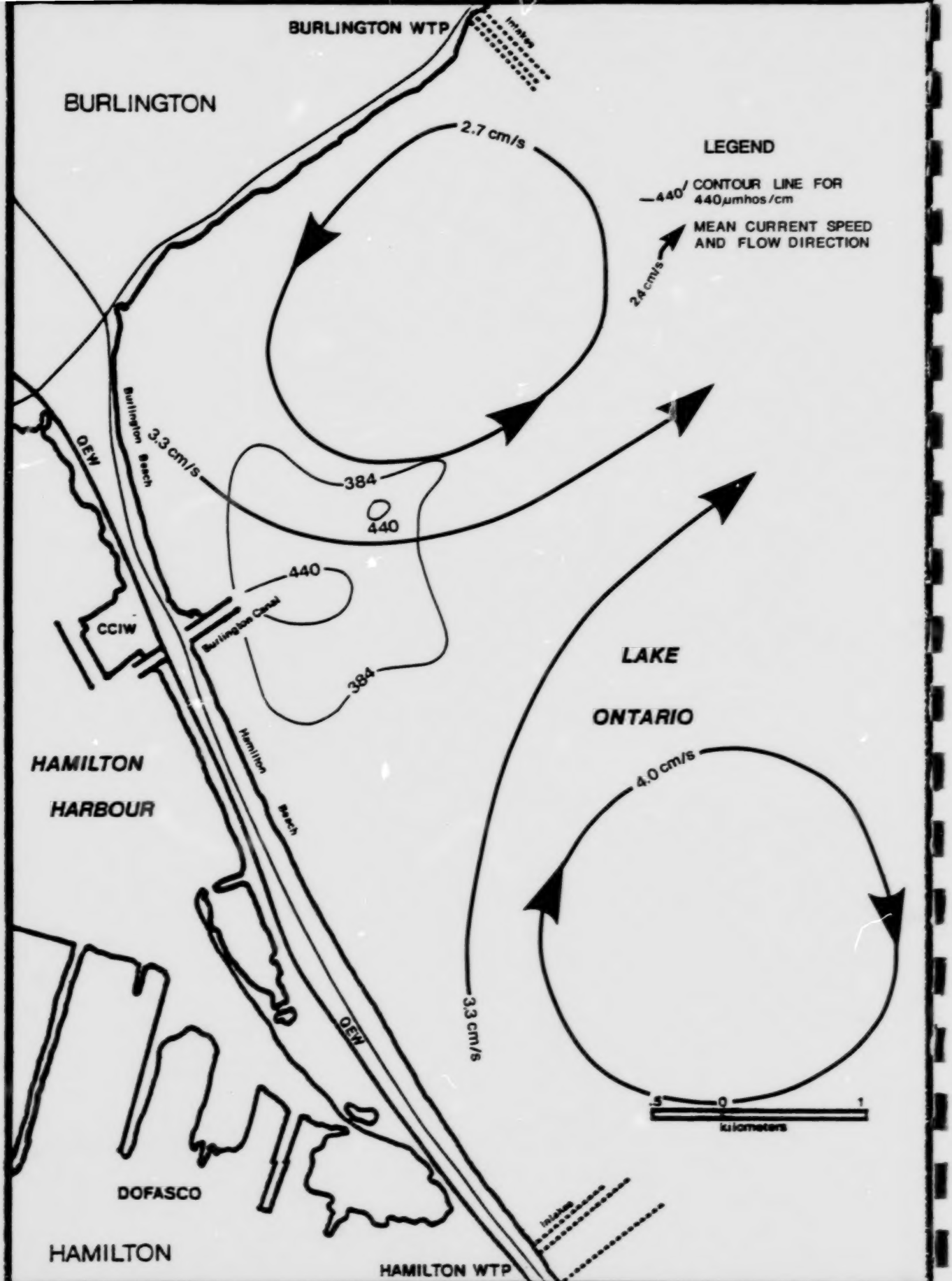

FIG 2.8: CONDUCTIVITY PLUME CONTOURS, 30 JUNE 1982, WESTERN LAKE ONTARIO

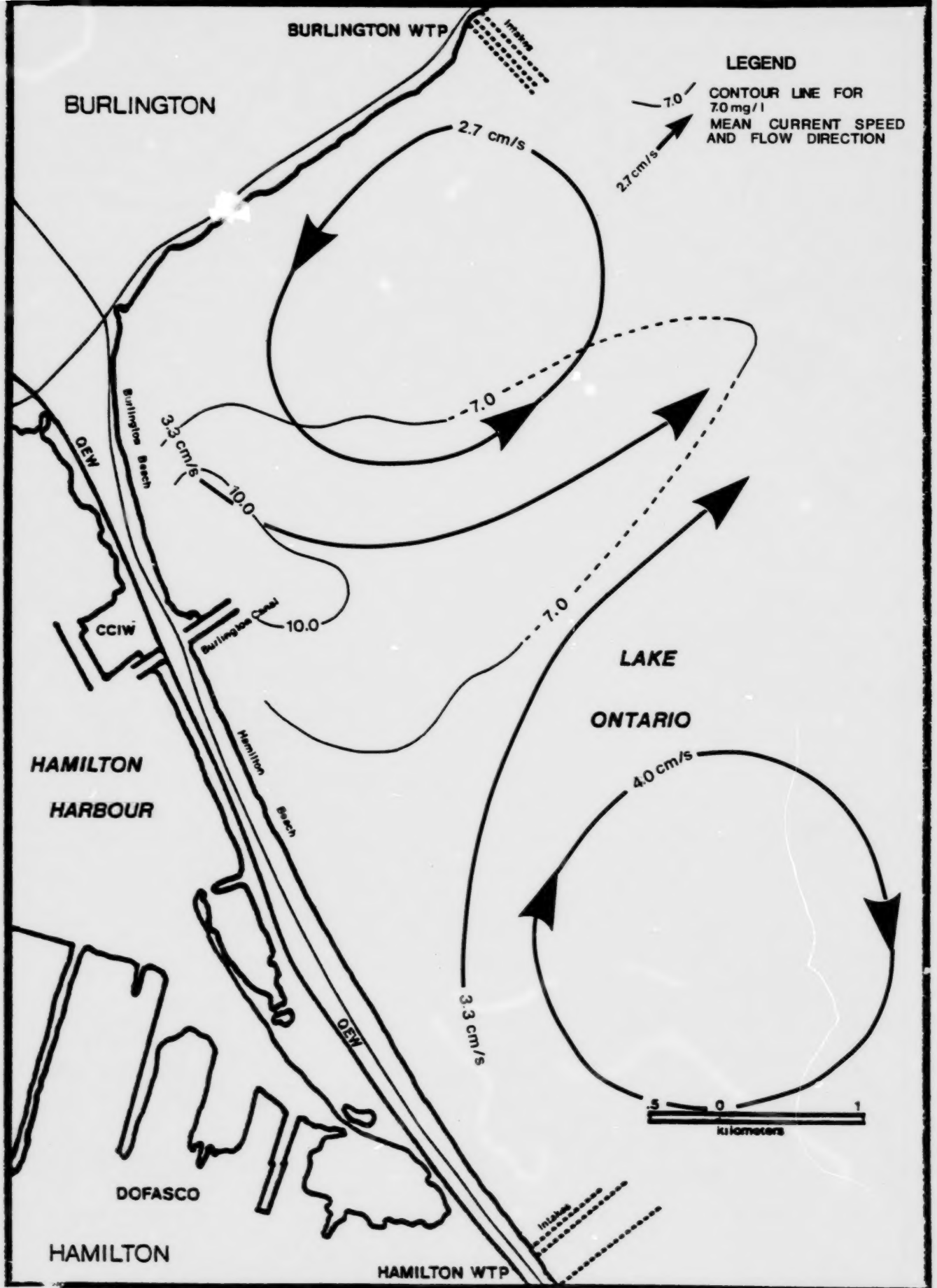

FIG. 2.9 : CHLOROPHYLL PLUME CONTOURS, 30 JUNE 1982, WESTERN LAKE ONTARIO

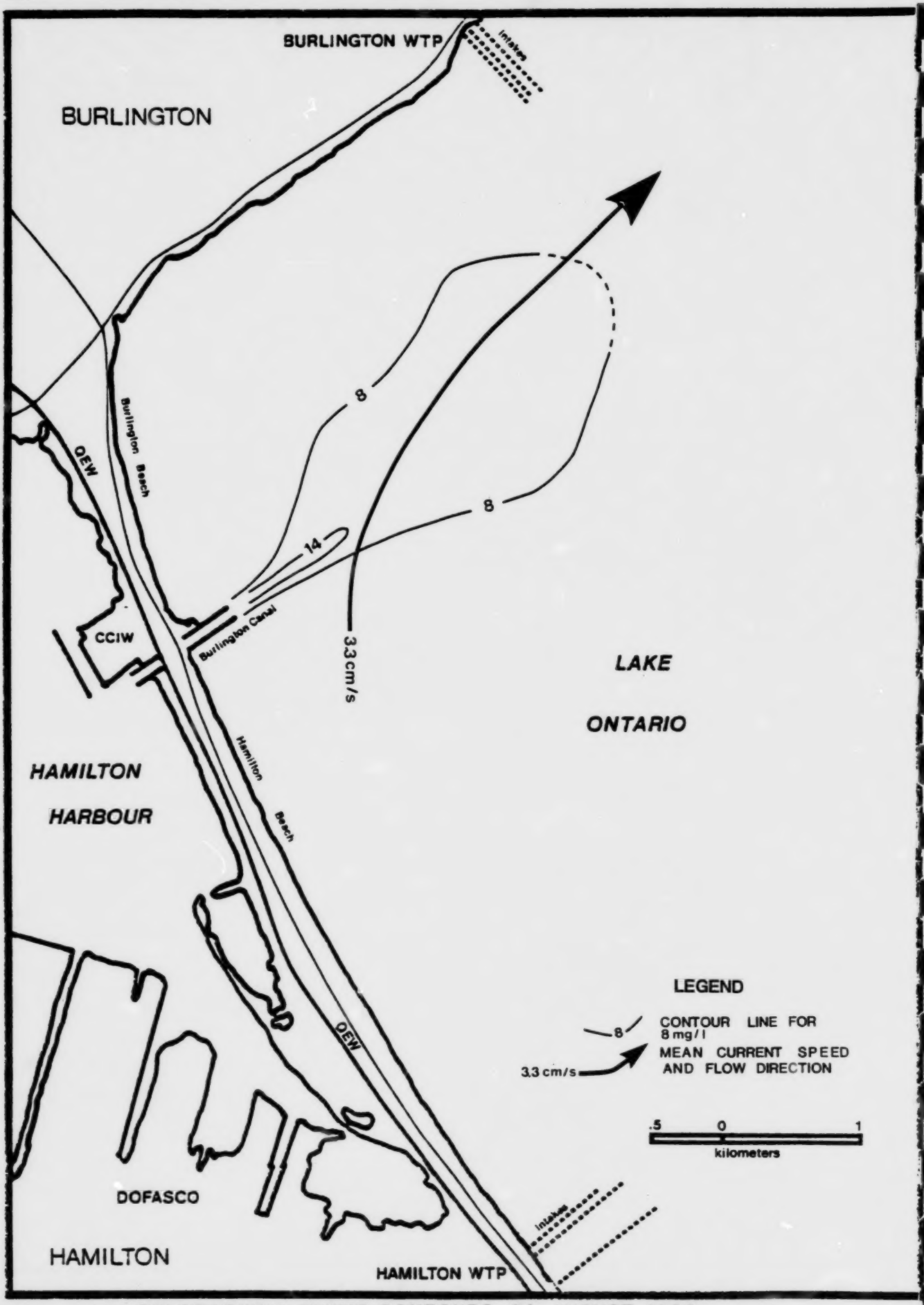

FIG. 2.10: CHLOROPHYLL PLUME CONTOURS, 24 AUGUST 1982, WESTERN LAKE ONTARIO

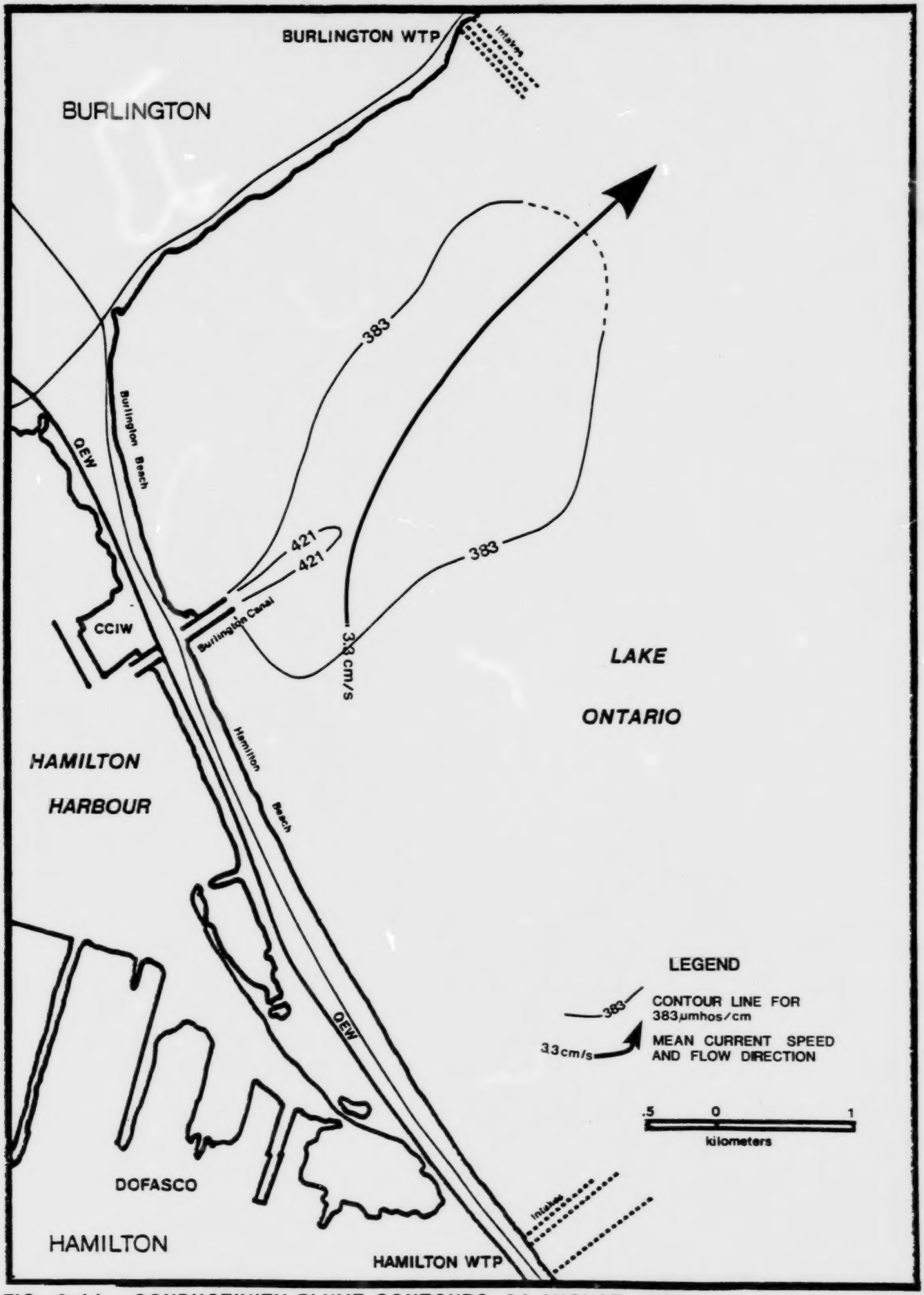

FIG 2.11 : CONDUCTIVITY PLUME CONTOURS, 24 AUGUST 1982, WESTERN LAKE ONTARIO

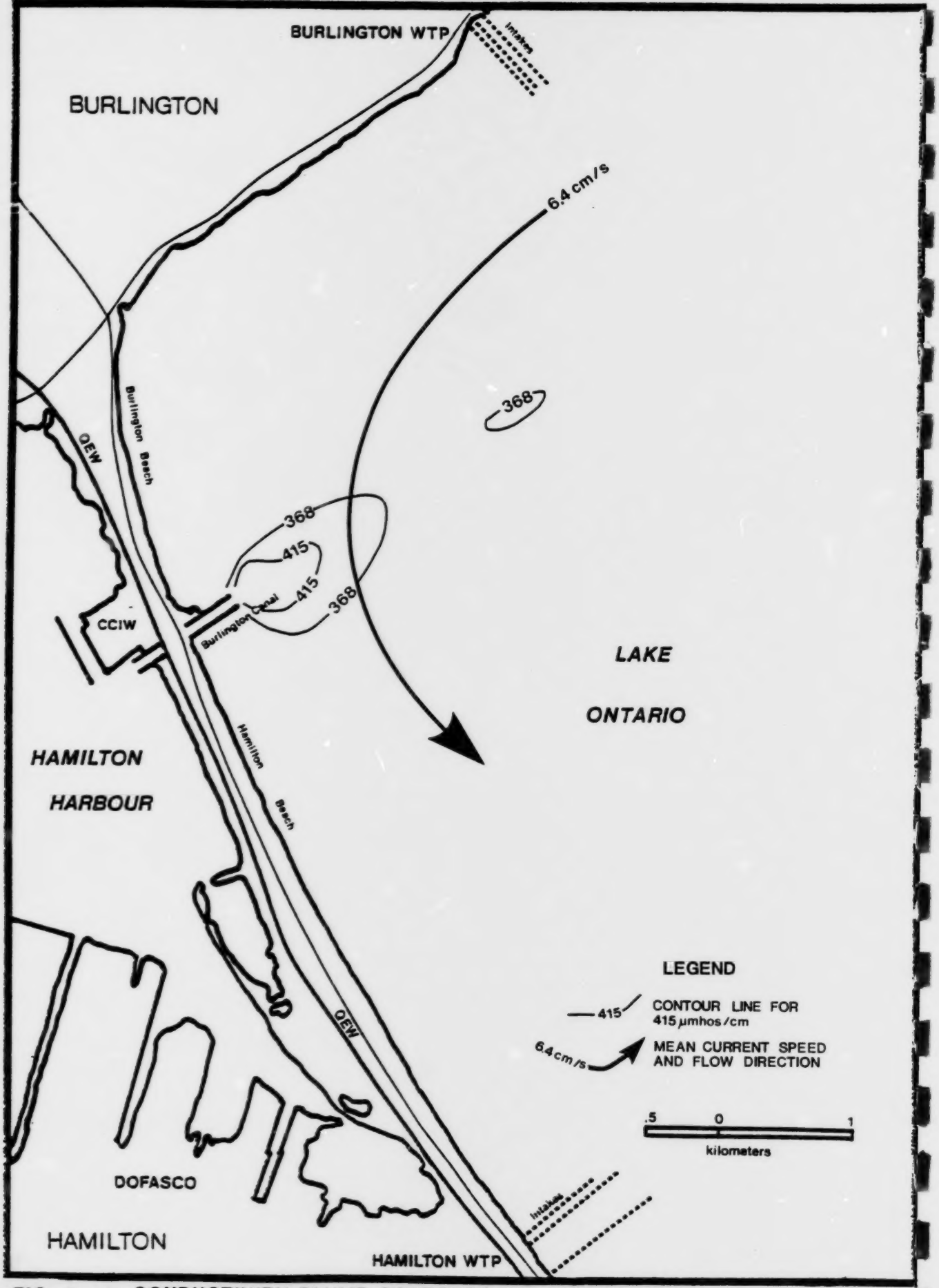

FIG 2.12: CONDUCTIVITY PLUME CONTOURS, 26 AUGUST 1982, WESTERN LAKE ONTARIO

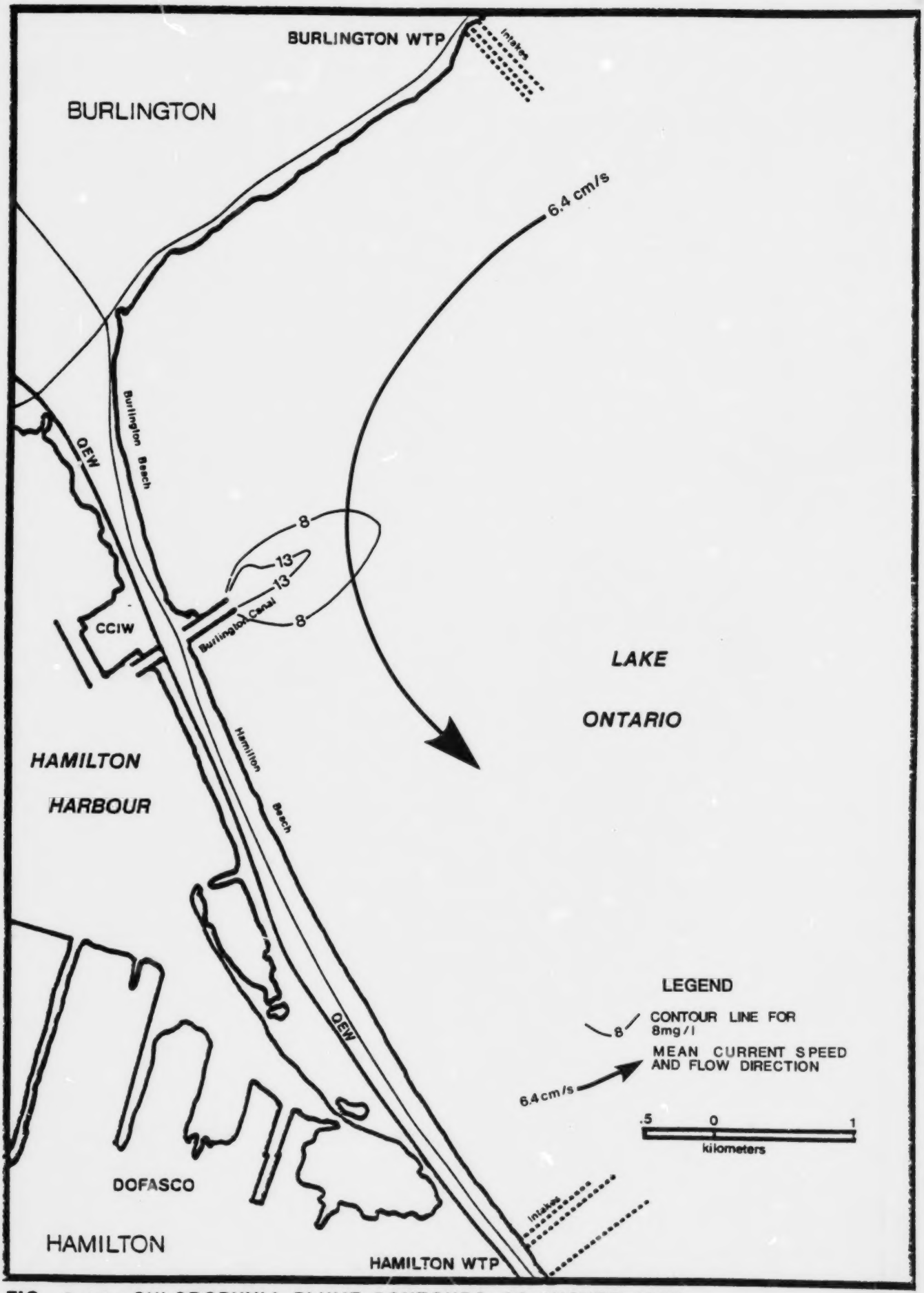

FIG 2.13 : CHLOROPHYLL PLUME CONTOURS, 26 AUGUST 1982, WESTERN LAKE ONTARIO

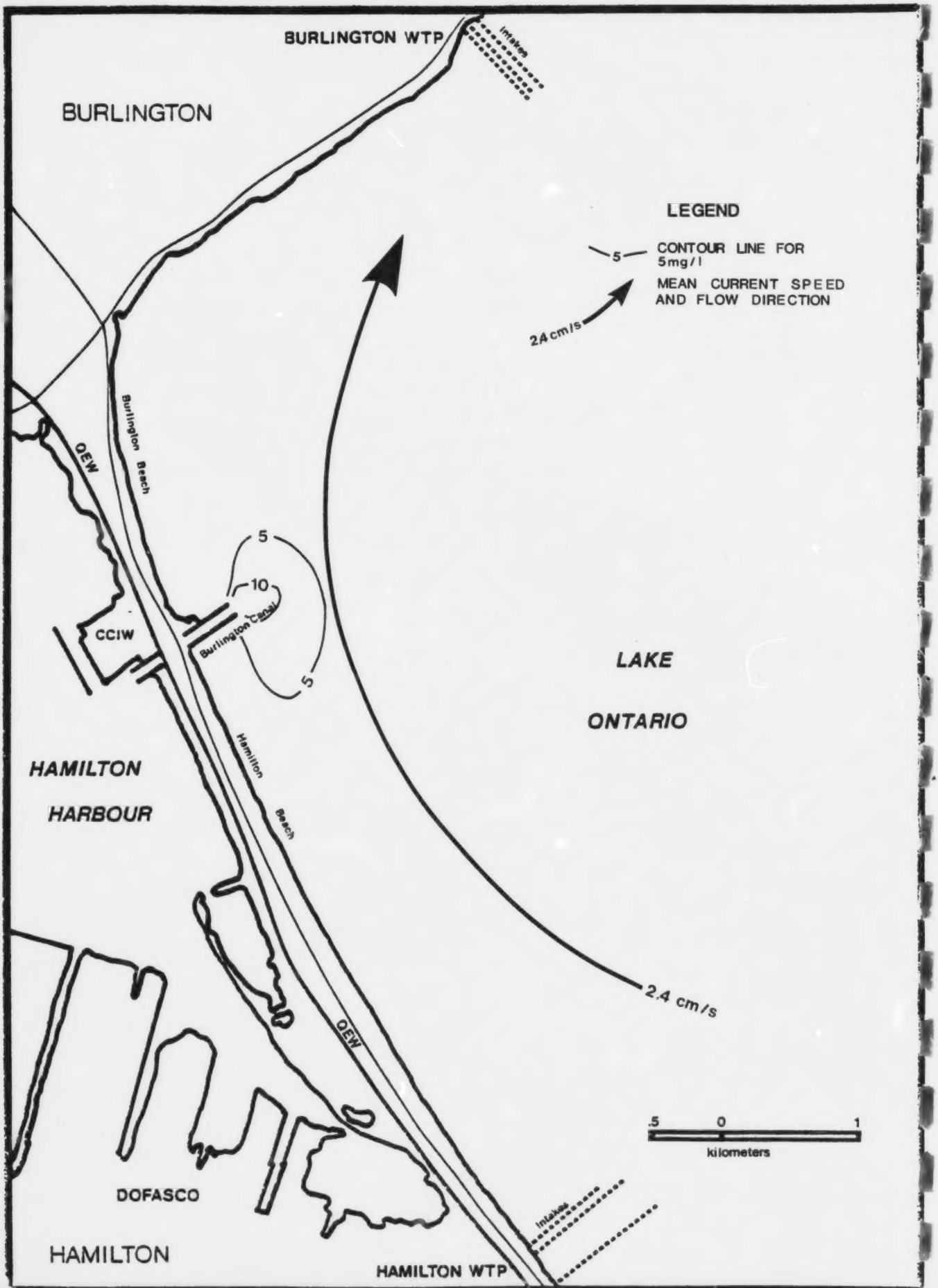

FIG. 2.14: CHLOROPHYLL PLUME CONTOURS, 22 OCTOBER 1982, WESTERN LAKE ONTARIO

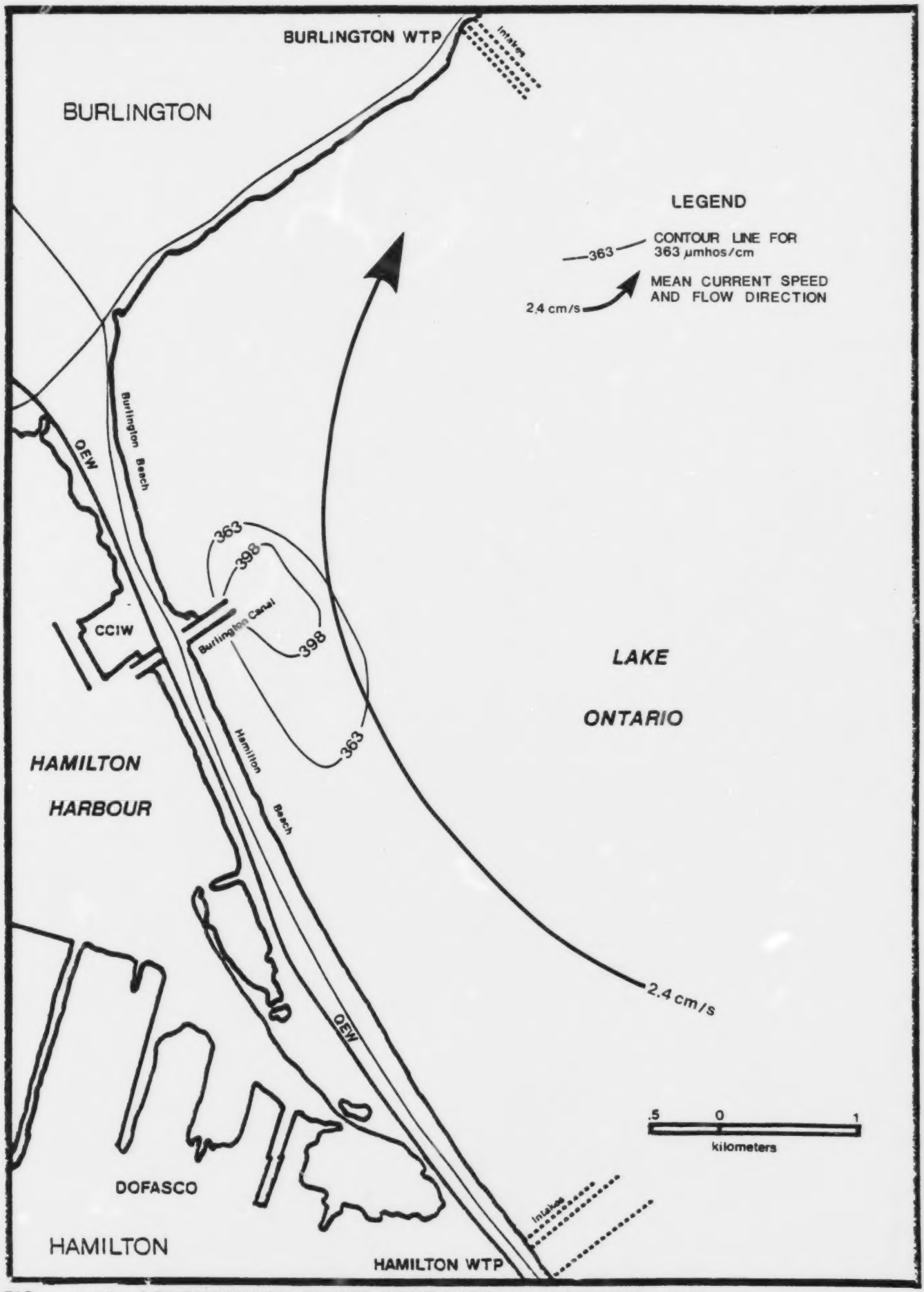

FIG. 2.15: CONDUCTIVITY PLUME CONTOURS, 22 OCTOBER 1982, WESTERN LAKE ONTARIO

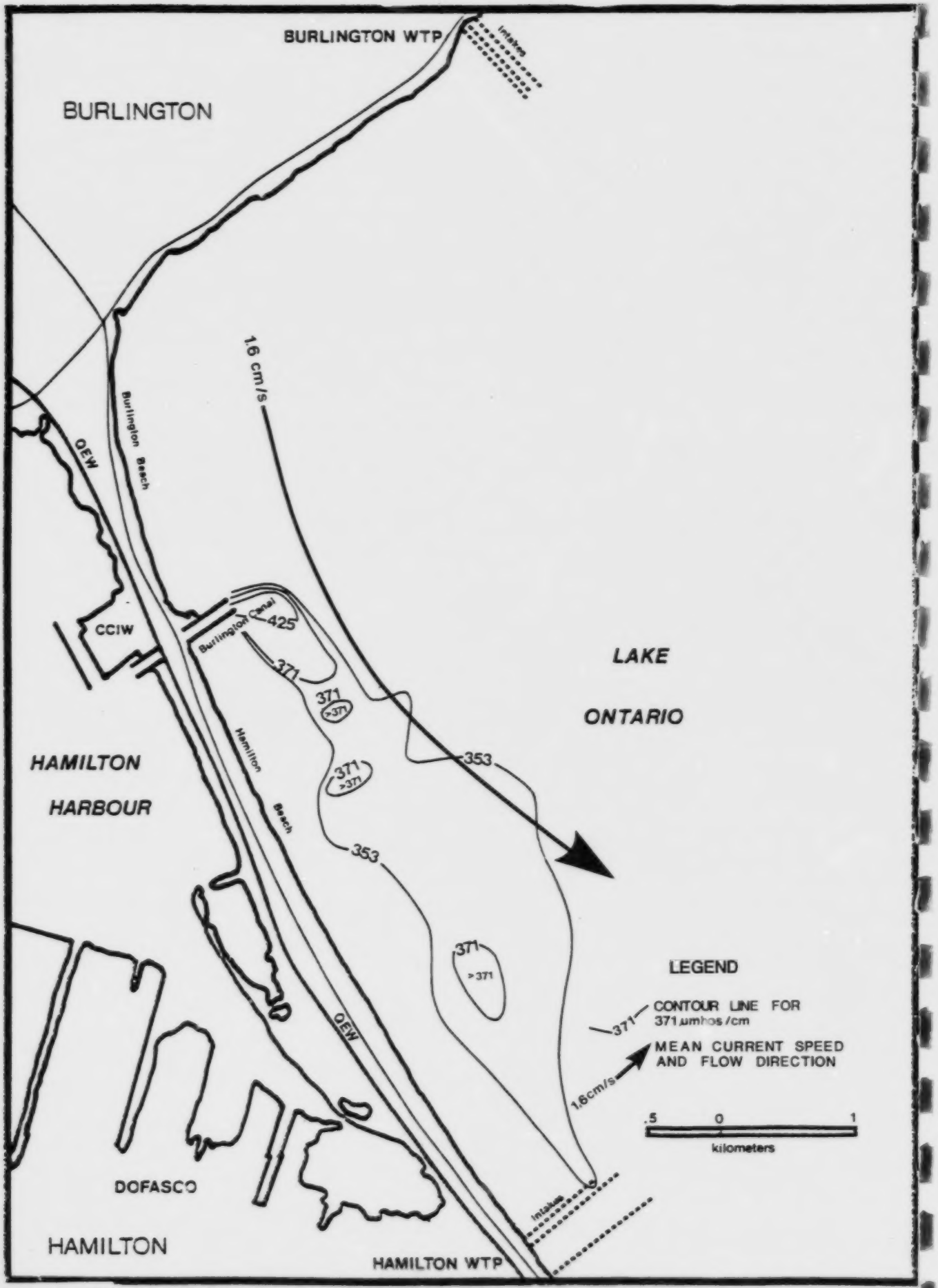

FIG. 2.16 : CONDUCTIVITY PLUME CONTOURS, 23 OCTOBER 1982, WESTERN LAKE ONTARIO

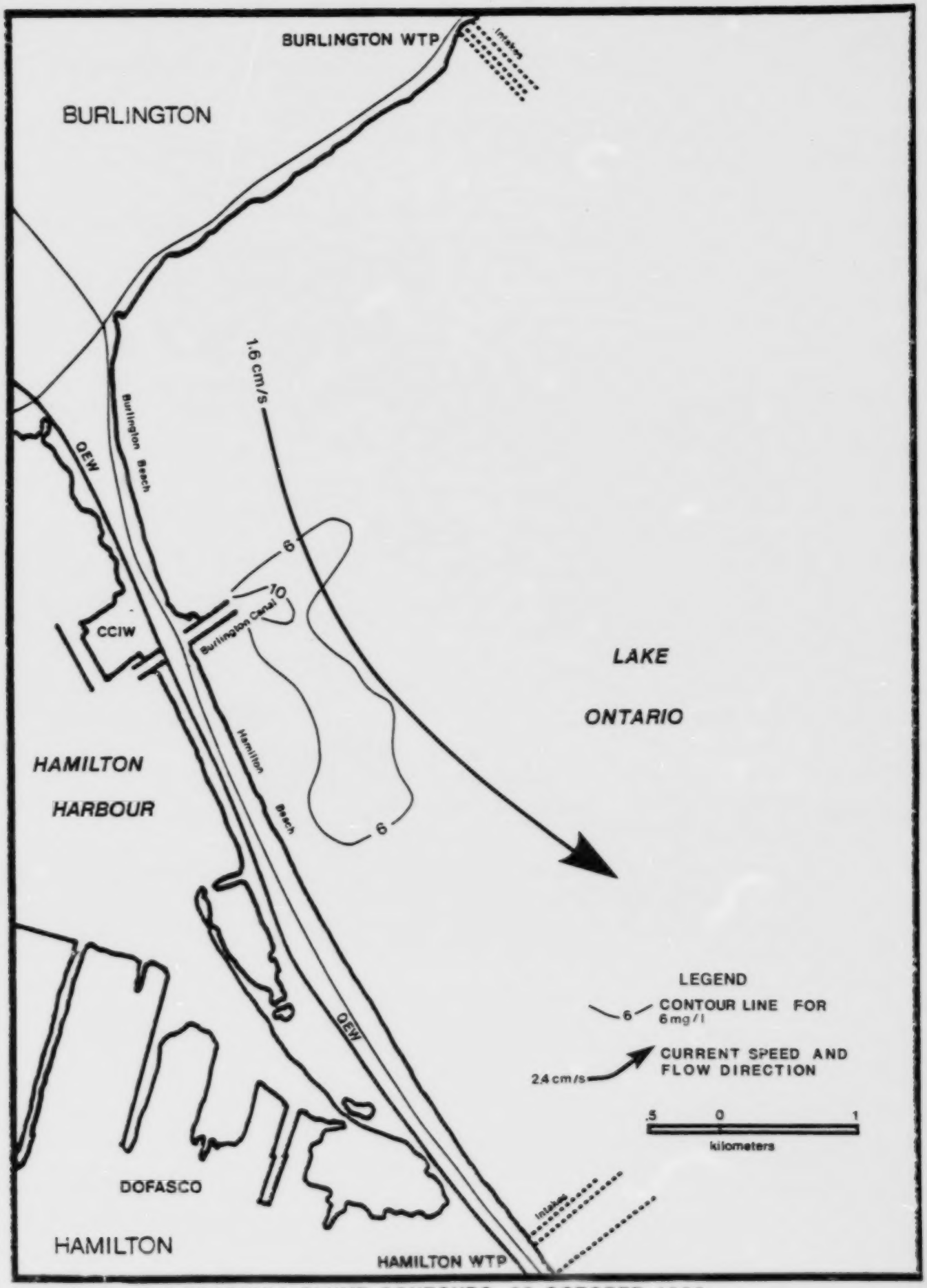

FIG. 2.17: CHLOROPHYLL PLUME CONTOURS, 23 OCTOBER 1982, WESTERN LAKE ONTARIO

3.0 BURLINGTON SHIP CANAL: PHYSICAL AND CHEMICAL PROFILES

3.1 Introduction

The first evidence of stratified flow in the Burlington ship canal was found by Matheson (1963), who detected a layer of warm harbour water flowing toward the lake at the surface above a layer of colder lake water flowing into the harbour. Dick and Marsalek (1973) measured temperature and velocity profiles and estimated mass exchanges to be approximately 5×10^4 kg/sec.

In 1972-73, as part of the initial Hamilton Harbour Study, two shore-mounted water chemistry monitors were operated at the ship canal to record water chemistry, with intakes at 3.6 and 6.7 m above bottom. Current meters were operated at similar depths. (MOE 1974; Palmer and Poulton 1976). Results of these studies showed that the lake-harbour exchange mechanisms were far more complicated than thought by previous investigators. At times, the various chemical measurements were strongly correlated, indicating plug flow through the canal into the lake or harbour. The time variation of both currents and chemistry was controlled by lake and harbour oscillations, with the former producing periodicities very similar to those theoretically calculated, at 5.1, 3.1, 2.3, 2.0, 1.7 and 1.4 hours as well as shorter periodicities, and the latter producing high-frequency variations of parameters such as temperature and dissolved oxygen. Occasionally, reversed flow was detected (inflowing lake water above outflowing harbour water), according to conductivity, pH and dissolved oxygen results. Three-layer flow was also occasionally found.

Palmer and Poulton (1976) also estimated rates of mass exchange in the canal from current meter records. During an isothermal (plug flow) period, a mass flow of 5.7×10^{10} kg to the lake and 3.4×10^{10} kg to the harbour occurred in a 10-day period. This represents a net exchange of about 1% of the harbour volume per day, an exchange which is important in maintaining harbour water quality and providing dissolved oxygen to the hypolimnion.

Currents were measured at three depths in the canal from May 1979 to April 1980. Kohli (1984) developed a mathematical model for flows through the canal, which accounted for excursions of lake water within the canal that did not clear the length of the canal because of rapid reversals in current direction. He calculated an average excursion distance of lake water into the harbour of 1018 m, with a range of values from 480 to 1562 m. The average net flow of harbour water to the lake for this period was 6.46×10^5 m^3/d, which is approximately equal to input flows from the municipal sewage treatment plants, storm water flows, flows from Cootes Paradise and from turbulence. The total average flow from the harbour to the lake was 3.3×10^6 m^3/d, which represents an average residence time of the harbour of about 90 days.

3.2 Field Procedures

The canal portion of the study consisted of two phases: (a) current measurements from the Burlington lift bridge, and (b) water chemistry profiling in the canal. Each will be discussed in turn.

Currents were measured by deploying an Aanderaa current meter from the lift bridge at a location near the center of the canal. Preliminary tests using four current meters operated simultaneously showed that no significant difference existed between mid-canal currents and those within 2 m of the canal wall. The meters were set to record data (speed, direction and temperature) at 2-minute intervals. Meter operation was monitored from the bridge continuously using a "digiprint" printer. This enabled continuous display of current direction. Currents were profiled at 2m depth increments from the surface to 8 m, with the meter kept at each depth long enough to record two valid sets of data per profile. Because speed is integrated by the meter over each 2 minute interval, the reading after each depth change was not valid; therefore, each depth took at least 6 minutes to complete, and longer if the bridge was raised for ship passage. Between 8 and 15 current profiles were obtained for each survey day.

Water chemistry was profiled from a boat anchored near the canal wall. A submersible pump was used to supply water to temperature, conductivity and fluorescence cells on board the boat. The fluorometer was set up to read chlorophyll concentration, as this was felt to be a potentially good tracer of harbour water due to its high chlorophyll a value. Water samples were collected for chlorophyll a analysis frequently and at as wide a fluorescence range as possible, for calibration purposes. The water column was profiled at 1-m intervals, continuously while currents were flowing out to the lake and less frequently when inflowing currents (to the harbour) were occurring. As no datalogging facilities were available, all data were hand-recorded for later transcription onto coding forms and keypunching. In addition, water chemistry samples were taken at 2-m depth intervals about once every 2 hours during outflowing currents. These were analyzed for ammonia, total Kjeldahl N, nitrate + nitrite-N, total phosphorus, filtered reactive phosphorus, chloride, turbidity, suspended solids, copper, iron, manganese and zinc.

Profiling from the bridge and canal boat was conducted on each survey date from about 2h before the plume-tracking boat passed through the ship canal, until about 1h before plume tracking was completed.

3.3 Data analysis procedures

The bridge currents and canal boat chemistry data were edited and compiled in a format suitable for calculating short-term loadings from the harbour to the lake. A synoptic data set suitable for entry into a plume model was also produced. Details for these procedures are found in a separate report (Senyshyn 1984) and are summarized here.

Chlorophyll was estimated for each sampling date using multiple regression of chlorophyll (from calibration samples) against fluorescence, temperature and time. Results of the regressions are given in Table 3.1. As expected, the largest portion of the variance was explained by fluoresence; temperature and time only occasionally provided significant ($P < 0.05$) results.

Conductivity (measured at ambient temperature) was corrected to 25°C using the relationship:

$$\text{cond (25°C)} = \text{cond (T°C)} \; (1.8892 - 0.04986T + 5.646 \times 10^{-4} \; T^2 + 3.284 \times 10^{-7} \; T^3)$$

Current meter results were edited to remove erroneous data obtained during depth changes or operation of the lift bridge, and duplicate readings at each depth averaged. Most duplicate readings agreed within reasonable limits except during current reversals. Current speeds were considered as positive for water flowing towards the lake, and negative for water flowing towards the harbour. These currents were then linearly interpolated to the times of water chemistry profiling from the canal boat; these interpolated currents were used in sorting the data into sets representative of inflowing and outflowing water, and estimation of short-term pollutant loadings to the lake.

The homogeneity of water masses flowing in either direction was tested using analysis of variance and covariance on the partial profiles. All statistical analyses were performed using SAS programs (Helwig and Council 1979).

3.4 Discussion of Results: Physical Profiles

The field program outlined in Section 3.2 produced a large amount of profiling data, from which several days of typical results will be discussed in some detail. As could be expected, the most highly stratified conditions occurred in August, with harbour water flowing to the lake at the surface and lake water flowing to the harbour at the bottom. In the other months, flow through the canal was mostly plug flow (same direction at all depths), although some thermal stratification did exist much of the time, even during plug flow. Interestingly enough, on one October survey date, the flow regime was almost as stratified as in August.

3.4.1 Profiles - June 29

Figures 3.1 a-f show current, temperature and conductivity profiles observed on June 29. Bridge data are found in Figures 3.1 a-b and canal data in Figures 3.1 c-f. Temperature data obtained from the bridge current meter and the canal chemistry meter were similar; both showed moderately strong stratification with temperature differences of 7 to 10°C from surface to bottom. Most of the difference was found in the bottom 2 or 3 m of the water column. Despite the stratification, current flow was largely unidirectional (plug flow). Flow was initially to the lake, reversing during profile 3 at 1131 h. Except for a brief interval of stratified flow observed during profile 5, flow to the harbour occurred until a gradual reversal during profile 8 at 1356-1408h. The irregular appearance of this profile showed that reversal did not occur simultaneously at all depths. Lakeward flow then occurred at all depths, with stratified flow occurring in profiles 11-12 at 1558-1648h, at which time complete reversal had again occurred. The interval between the two reversals from outflowing to inflowing conditions was approximately 5 h and thus represents the first longitudinal oscillation period of Lake Ontario (Palmer and Poulton 1976). Thus, canal flows appear to be driven primarily by lake oscillation, with thermal stratification playing a minor role at this time of year.

Most conductivity profiles on June 29 showed a depth dependence similar to that of temperature, with lowest values in the bottom 2-3m of the water column. Upper layer results (approx. 600 umho/cm) were indicative of harbour water nearly all day; however, no profiles were taken during most of the inflow period. Profile 4 was taken at 1124-1142h, i.e. during reversal to inflow conditions, and profile 5 was taken at 1354-1406h, during reversal to outflow conditions. This latter profile was the only profile that showed evidence of mixed harbour-lake water at mid-depths. Profile 10 was obtained just after reversal to inflow at 1656-1712h, but still showed harbour conditions. This indicated that insufficient time had elapsed for lake water entering the canal from the lake to displace harbour water at the location of the canal boat (mid-canal).

Chlorophyll a profiles (not shown) exhibit a gradual decrease with depth from 12-18 ug/L at the surface to 6-10 ug/L at the bottom.

3.4.2 Profiles - August 26

Figure 3.2 shows current, temperature and conductivity profiles obtained on August 26. At the beginning of current measurement (0858h), flow of lake water towards the harbour was occurring at all depths, with the thermocline at around 4 m. Surface water flow reversal had begun by profile 2 (0939h), with surface conductivity in canal profile 1 (0935h) also signalling the event. The remainder of the water column at this time had temperatures (9-10°C) and conductivity (340-360 umho) characteristic of upwelled lake water. Complete reversal occurred within the next 32 min, shown by current profile 3 (1011h at surface). Canal profile 2 (1054h) and bridge profile 4 (1043h) showed the beginning of progression towards stratified flow, which was well developed by bridge profile 6 (1157h) and canal profile 4 (1302h). The stratified flow was characterized by current speeds up to 26 cm/s towards the lake at the surface and up to 23 cm/s towards the harbour at the bottom, and by a temperature difference of 10°C between surface and bottom. Surface water conductivity and chlorophyll were 520 umho/cm and 18-24 ug/L respectively, while bottom water values were 340 umho/cm and 7-13 ug/L. A rapid variation in all parameters occurred at water depths between 3 and 5 m, showing strong stratification and a well-developed shear plane. Maximum surface chlorophyll was similar to that at station 258 in the central basin of the harbour (25 ug/L), and the observed spread probably reflects reduced photosynthesis in rapidly flowing canal water as well as the questionable accuracy of the chlorophyll-fluorescence relationship (Senyshyn 1984).

The well-stratified flow persisted for over 4 hours, with reduced stability being indicated by a bottom shift to lakeward flow at the end of profile 12 (1607h). A period of lakeward flow at all depths (over 30 cm/s at surface, but below 15 cm/s at 6-8m depth) persisted until 1713h (bridge profile 14) when a return to stratified flow commenced at

the end of the survey day. This was about 5.2h after the previous start of well-stratified flow (bridge profile 6, 1157h), reflecting the influence of Lake Ontario oscillations on the canal, as discussed earlier.

Canal profiles 9 and 10 (1614 - 1713h) also give evidence of this period of weakened stratification and lakeward flow, with conductivities at 5 to 7m depth representative of a mixture of lake and harbour water.

3.4.3 Profiles - October 19 and 22

Figures 3.3 and 3.4 illustrate currents, temperature and conductivity on October 19 and 22. Results show variations from lake conditions at all depths to harbour conditions at all depths, and intermediate variations with rapid flow reversals.

At the beginning of bridge profiling (0930h), harbour water was flowing to the lake at the surface; this immediately reversed (0936h), although temperatures remained high except at the bottom. Inflow towards the harbour persisted through bridge profiles 2 and 3, with speeds of 15 to 30 cm/s, although water temperatures similar to harbour conditions continued until the 4 m depth of profile 2 (1026h). This suggested an excursion time of 50 minutes before lake water conditions were observed at the lift bridge. Canal boat temperature and conductivity profiles showed stratified conditions at this time in profiles 1 (1005-1018h) and 2 (1029-1048h), but with a progression towards lake water conditions, which were found throughout the water column at profile 3 (1110-1121h). By the end of this time, a reversal to lakeward flow was beginning, as shown by current profile 4 (1122h), although lake water temperature was observed for the complete profile and was changing at the start of current profile 5 (1148h)(current speed 30 cm/s). This showed an excursion time of about 26 minutes. Harbour water was next observed by canal profile 4, for 1220-1235h, at all depths, and by bridge current profile 6 at the same time. At the bottom of bridge profile 6, the currents reversed again towards the harbour (1254h).

The afternoon of October 19 produced continued rapid reversals of currents, with profile 7 (1308-1332h) showing water flowing to the harbour, profile 8 (1339-1418h) illustrating lakeward flow except at the bottom level, while profiles 9 and 10 (1436-1540h) revealed water flowing to the harbour. Comparison of currents and temperature near the bottom suggest excursion times of about 30 to 40 minutes (bridge profiles 6 and 7). Conductivity results suggested the existence of mostly harbour water in the top 4 m or so of the water column and lake water (or near to lake conditions) at the bottom, with changing conditions 5 to 7m above bottom. In the upper 4m of the water column, the current reversals occur faster than the excursion time, with conductivity, temperature and chlorophyll results all suggestive of harbour water, or at least a mixture containing mostly harbour water, in this part of the water column all afternoon. This suggests that the rapid reversals merely bring a portion of the harbour plume back into the canal.

The current profile of October 19 was thus one of largely plug flow, complicated with rapid reversals of the order of 1.5 to 3 h in duration. This was apparently controlled by higher-order lake oscillations (3.2, 2.3, 2.0, 1.7 h: Palmer and Poulton 1976), independent of true thermal stratification.

By contrast, on October 22, largely stratified flow through the canal was observed, with a continuous temperature gradient of about 6^{o} from the surface to the bottom. Conductivity values representative of harbour water were found continuously at the surface, although two brief flow reversals did occur. At the bottom, likewise, conductivity values representative of lake water generally occurred, although some oscillation in the thermocline depth did occur in response to lake oscillation induced shifts in current direction and speed. The existence of stratified flow this late in the fall was not anticipated.

Currents on October 23 were largely reversing plug flow without stratification, similar to those on October 19.

3.5 Discussion of Results: Chemical Profiles

On each survey day in June, August and October, three or four series of chemical samples were taken at 2-m depth intervals from the surface to 8m. These were generally taken under outflowing or stratified flow conditions. All samples were analyzed for ammonia, total Kjeldahl nitrogen, nitrite plus nitrate nitrogen, total phosphorus, filtered reactive phosphorus, chloride, turbidity, suspended solids, copper, iron, manganese and zinc. The primary purpose of the chemical sampling was to determine short-term loadings from Hamilton Harbour to Lake Ontario. These loadings are discussed in section 3.6. Samples in May included only a few samples from two or three depths and were insufficient for proper analysis. They are not discussed further.

Profiles of ammonia and total phosphorus obtained on August 26 under stratified flow conditions are shown in Figure 3.5. The four profiles illustrated correspond to conductivity profiles 1, 3, 8 and 10 discussed in Section 3.4.2 and shown in Figure 3.2. Similar to conductivity, the profiles show the presence of concentrations typical of harbour and lake conditions during outflow and inflow respectively, with intermediate concentrations being obtained after flow reversal, or at depths near the shear plane of stratified flow.

An example of chemistry under reversing plug flow conditions is shown in Figure 3.6 for October 19. The three profiles correspond to canal profiles 2,4 and 9 discussed in Section 3.4.3 and illustrated in Figure 3.3. As discussed in Section 3.4.3, the reversals were occurring rapidly enough on that day, causing inflowing water to appear stratified with surface water approaching harbour conditions and bottom water approaching lake conditions. The hypolimnion contained an appreciable fraction of harbour water.

The chemical properties of epilimnetic (0-6m) harbour (station 258) and outflowing epilimnetic canal water are compared on a month-to-month basis in Tables 3.2-3.4. Canal samples containing mixtures of lake and harbour water were deleted from the data set before the statistics were computed.

In August, under conditions of maximum thermal stratification, nearly all chemical parameters showed significantly ($P \leq 0.05$) higher concentrations in the canal, compared to station 258, in the centre of the harbour. This suggests that some short-circuiting of water from the Hamilton STP or industrial sources in the southeastern part of the harbour was occurring. By contrast, in October, no significant difference between harbour and canal was found, except for suspended solids, for which harbour concentrations were higher than canal concentrations. Apparently, thermal stratification in the harbour plays a significant role in determining whether or not short-circuiting occurs. The result for June is less clear. While ammonia-N, TKN, chloride and copper show significantly higher concentrations in the canal, similar to August, Total P and FRP show significantly higher concentrations in the harbour. The other parameters show no significant difference. Thus the picture in June is less conclusive. These results may be due to weaker stratification in the canal resulting in more mixing, physical or biological conditions in the harbour, or both. As fewer harbour samples were collected in June, compared to August or October, it is difficult to draw any conclusion from the data collected in that month.

3.6 Loadings to the Lake

Pollutant loads to and from the harbour were calculated separately for each depth "layer" in the canal (i.e., 2m to 4m depth; 4m to 6m depth, and so on). The load for each layer was considered to be the cross-sectional area of the layer, multiplied by the velocity of flow and the pollutant concentration within it:

load = layer width x layer depth x current velocity x pollutant concentration

Since currents moving towards the lake were assigned positive values and those toward the harbour were given negative values, the loads to and from the lake are similarly designated as positive or negative. The "total load" (net load) is the sum of all layer loads, including both outflowing and inflowing conditions. The total load to the lake is the sum of all loads flowing to the lake and does not take into

account return flows to the harbour. Average total loads are calculated as the sum of all total loads for a survey day, divided by the number of profiles obtained. Zero values were excluded from these calculations. The results show that, in general, total loads are variable in mass and direction, both within a survey day and from one day to another (see sections 3.4 and 3.5).

In the majority of profiles (28 of 38 for most parameters) the net transport of pollutants was from the harbour to the lake; in only 10 of 38 was the trend clearly towards the harbour. The latter condition was found throughout the survey period and did not appear to be associated with a particular season or time of day.

The magnitudes of the pollutant loadings are similar to those estimated by Poulton (MOE 1985) from 1979 data. Table 3.5 indicates the 1979 and 1982 loadings to and from the harbour for some representative parameters. These were calculated excluding results representative of data collected during or immediately after reversals (i.e. within the excursion times as mentioned in sections 3.4 - 3.5). Table 3.5 also includes loadings from Niagara River to Lake Ontario (IJC 1985; Kuntz 1984). In all cases, the amount of contaminants contributed by Hamilton Harbour to Lake Ontario is small compared to the loadings from the Niagara River.

3.7 REFERENCES

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TABLE 3.1
CHLOROPHYLL - FLUORESCENCE CALIBRATION CURVES
BURLINGTON SHIP CANAL

Date	# Obs.	Variable	Regression Coefficient	Significance of F	Significance of t	R^2	Standard Error
82/05/20			DATA NOT VALID				
82/05/21	5	Intercept	-19.303		0.1036	0.915	6.155
		Fluorescence	1912.404	0.0108	0.0108		
82/05/24	10	Intercept	2.052			0.830	2.6675
		Fluorescence	1656.853	0.0020	0.0020		
		Time	-0.017		0.0084		
82/06/28	12	Intercept	-13.664		0.0778	0.839	1.431
		Fluorescence	58.679	0.0837	0.0837		
		Temperature	0.5596	0.0192	0.0192		
82/06/29	9	Intercept	-14.487		0.1001	0.760	1.861
		Fluorescence	54.702	4.32	0.0829		
		Temperature	0.6800	10.40	0.0180		
82/06/30	11	Intercept	-37.251		0.1084	0.372	3.127
		Fluorescence	166.471	0.0465	0.0465		
82/08/24	14	Intercept	-15.603		0.0031	0.855	3.813
		Fluorescence	88.350	0.0001	0.0001		
82/08/26	9	Intercept	-20.326		0.1596	0.440	4.240
		Fluorescence	109.689	0.0515	0.0515		
82/08/27	16	Intercept	-16.861		0.0117	0.724	4.763
		Fluorescence	99.815	0.0001	0.0001		
82/08/28	13	Intercept	-20.399		0.0055	0.814	3.493
		Fluorescence	121.701	0.0001	0.0001		
82/10/19	15	Intercept	-4.484		0.0097	0.916	1.181
		Fluorescence	79.211	0.0001	0.0001		
82/10/22	20	Intercept	-3.180		0.0069	0.918	1.725
		Fluorescence	69.045	0.0001	0.0001		
82/10/23	20	Intercept	-4.955		0.0015	0.930	1.497
		Fluorescence	87.182	0.0001	0.0001		

TABLE 3.2

t-test of differences between station 258 (0-6m)
and outflowing canal (0-6m) water

(a) June

	Harbour			Canal			t	P
	N	Mean	SD	N	Mean	SD		
NH_3-N	6	2.09	0.11	22	2.62	0.22	-5.78	.01
TKN	5	3.12	0.63	22	3.61	0.36	-2.39	.05
(NO_2+NO_3)-N	6	2.52	0.08	22	2.43	0.10	1.81	NS
Total P	4	0.106	0.013	22	0.084	0.011	3.24	.05
FRP	6	0.049	0.010	22	0.031	0.008	3.75	.01
Cl	6	81.1	1.6	22	84.4	6.6	-2.12	.05
Turbidity	6	4.12	1.06	22	4.00	0.74	0.27	NS
Susp. Solids	6	3.05	0.83	22	3.81	0.64	-2.08	NS
Cu	5	0.005	0.001	22	0.007	0.002	-3.83	.01
Fe	6	0.223	0.056	21	0.257	0.056	-1.30	NS
Mn	6	0.045	0.010	22	0.050	0.006	-1.08	NS
Zn	6	0.033	0.012	22	0.027	0.004	1.09	NS

Note: All concentrations are in mg/L except turbidity (FTU)
t = value of "t" statistic
p = significance probability level of "t"
NS = not significant

TABLE 3.3

t-test of differences between station 258 (0-6m) and outflowing canal (0-6m) water

(b) August

	Harbour			Canal			t	P
	N	Mean	SD	N	Mean	SD		
NH_3-N	12	0.61	0.04	40	0.98	0.36	-6.33	.01
TKN	12	1.40	0.08	40	1.81	0.43	-5.67	.01
(NO_2+NO_3)-N	12	2.11	0.07	40	1.99	0.26	2.62	.05
Total P	12	0.047	0.005	40	0.059	0.012	-5.10	.01
FRP	12	0.013	0.007	40	0.019	0.008	-2.39	.05
Cl	12	53.8	4.2	40	60.1	6.6	-4.04	.01
Turbidity	12	3.05	1.19	40	4.93	2.64	-3.48	.01
Susp. Solids	12	3.96	1.16	40	5.85	2.72	-3.47	.01
Cu	12	0.006	0.002	40	0.008	0.005	-1.35	NS
Fe	12	0.087	0.029	40	0.278	0.154	-7.41	.01
Mn	12	0.023	0.004	40	0.031	0.015	-3.20	.01
Zn	12	0.035	0.049	40	0.020	0.019	1.01	NS

Note: All concentrations are in mg/L except turbidity (FTU)
t = value of "t" statistic
p = significance probability level of "t"
NS = not significant

TABLE 3.4

t-test of differences between station 258 (0-6m)
and outflowing canal (0-6m) water

(c) October

	Harbour			Canal			t	P
	N	Mean	SD	N	Mean	SD		
NH_3-N	8	1.58	0.23	29	1.71	0.19	-1.45	NS
TKN	8	2.18	0.36	29	2.33	0.31	-1.09	NS
(NO_2+NO_3)-N	8	1.70	0.25	29	1.69	0.20	0.11	NS
Total P	8	0.061	0.008	29	0.061	0.005	-0.05	NS
FRP	8	0.020	0.004	29	0.019	0.004	0.66	NS
Cl	8	56.1	4.7	29	53.7	4.5	1.31	NS
Turbidity	8	3.25	0.70	29	3.54	0.72	-1.03	NS
Susp. Solids	8	4.88	1.11	28	3.93	0.92	2.20	.05
Cu	8	0.006	0.001	29	0.008	0.007	-1.58	NS
Fe	8	0.575	1.064	29	0.380	0.465	0.50	NS
Mn	8	0.071	0.040	29	0.058	0.060	0.70	NS
Zn	8	0.018	0.009	24	0.018	0.005	0.13	NS

Note: All concentrations are in mg/L except turbidity (FTU)
t = value of "t" statistic
p = significance probability level of "t"
NS = not significant

TABLE 3.5

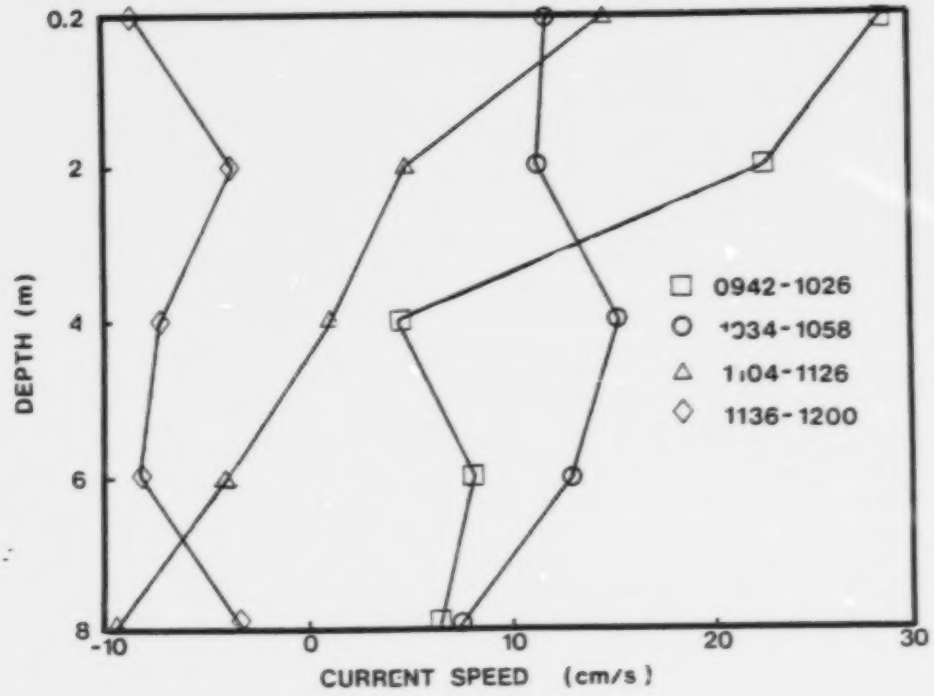
1979 and 1982 Pollutant Loadings from Hamilton Harbour

Parameter	1982 Gross Estimated Load to L. Ontario (10^6kg/yr)	1982 Gross Estimated Load from L. Ontario to Hamilton Harbour (10^6kg/yr)	1982 Estimated Net Load to Lake Ontario (10^6 Kg/yr)	1979 Net Load to Lake Ontario (10^6kg/yr)	1982 Load to Lake Ontario From Niagara River (10^6 kg/yr) (IJC 1985; Kuntz 1984)
NH_3	3.666	-2.056	1.610	-	-
Total N	9.489	-5.311	4.178	5.5	49.3*
Total P	0.142	-0.076	0.066	0.122	4.87
FRP	0.099	-0.063	0.036	-	-
Chloride	137.035	-86.165	50.870	-	-
Susp. Solids	10.054	-6.492	3.562	5.8	2100.0
Copper	0.011	-0.023	-0.012	-	0.41
Iron	0.632	-0.558	0.074	0.194	79.4
Manganese	0.093	-0.076	0.017	-	4.0
Zinc	0.046	-0.037	0.009	-	0.61

Note*: Loading for nitrate-N.

FIG. 3.1a : DEPTH PROFILES OF CURRENTS IN BURLINGTON SHIP CANAL JUNE 29, 1982

(a) 0942-1200 h



(b) 1206-1344 h

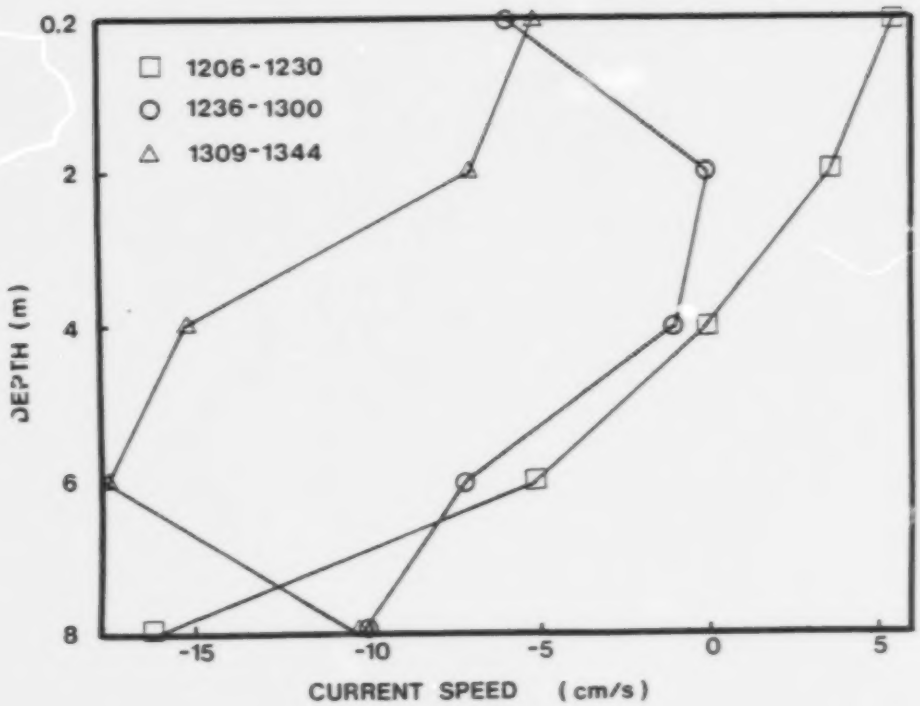
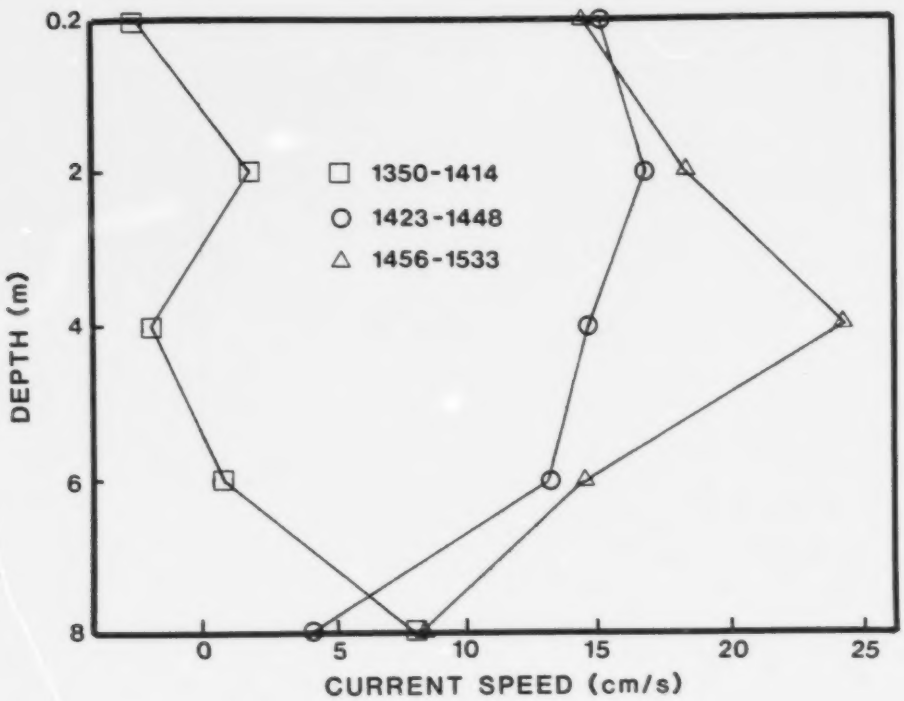


FIG.3.1b : DEPTH PROFILES OF CURRENTS IN BURLINGTON SHIP CANAL, JUNE 29, 1982

(c) 1350-1533



(d) 1540-1728

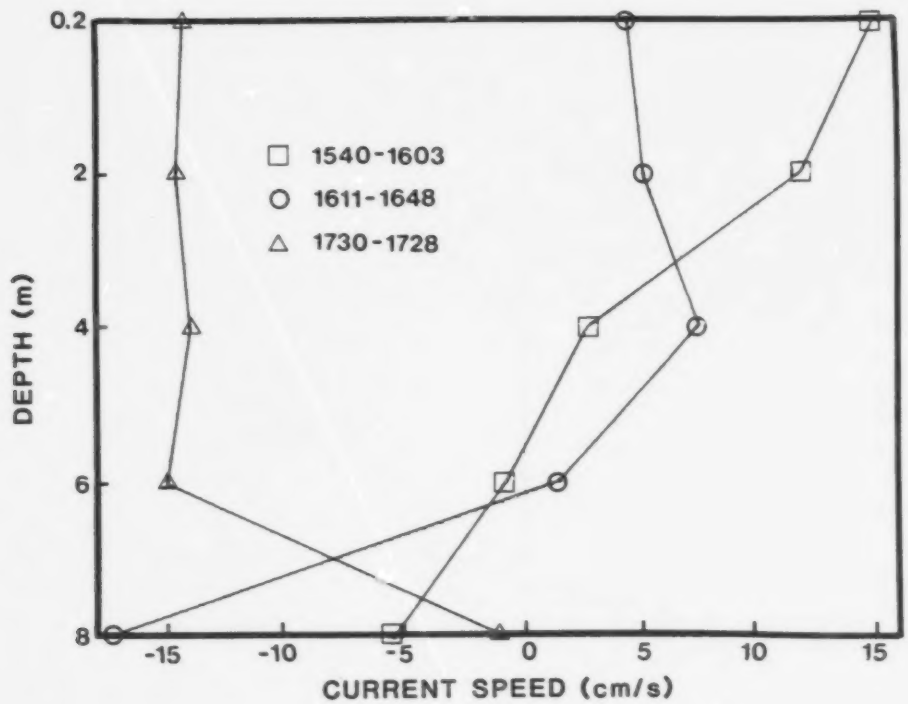
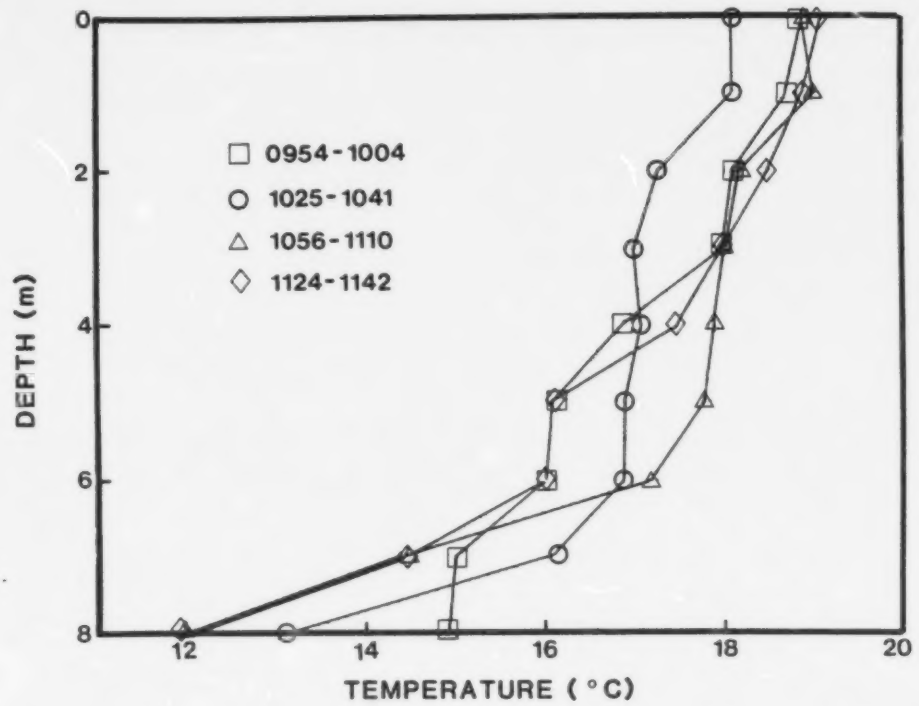


FIG. 3.1c : DEPTH PROFILES OF TEMPERATURE IN BURLINGTON SHIP CANAL, JUNE 29, 1982

(a) 0954-1142



(b) 1354-1512

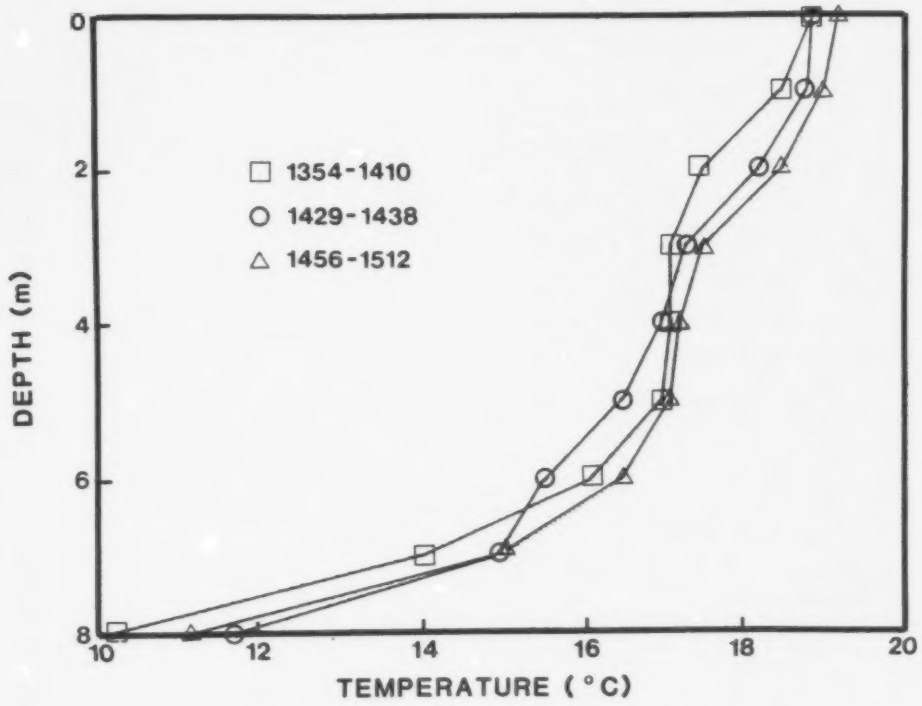


FIG. 3.1d : DEPTH PROFILES OF TEMPERATURE IN BURLINGTON SHIP CANAL, JUNE 29, 1982

(c) 1532-1712

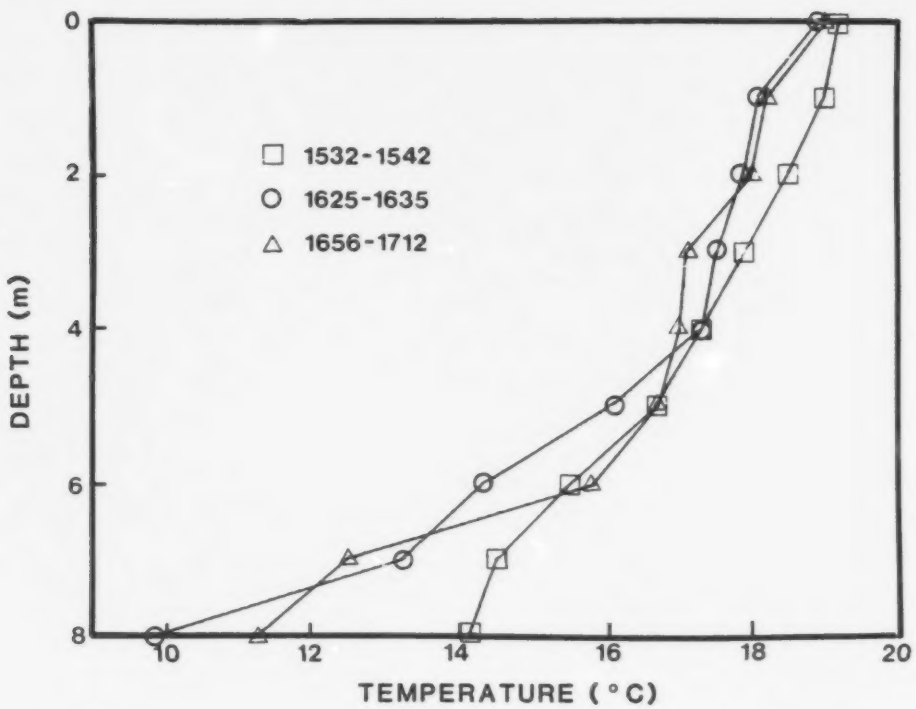
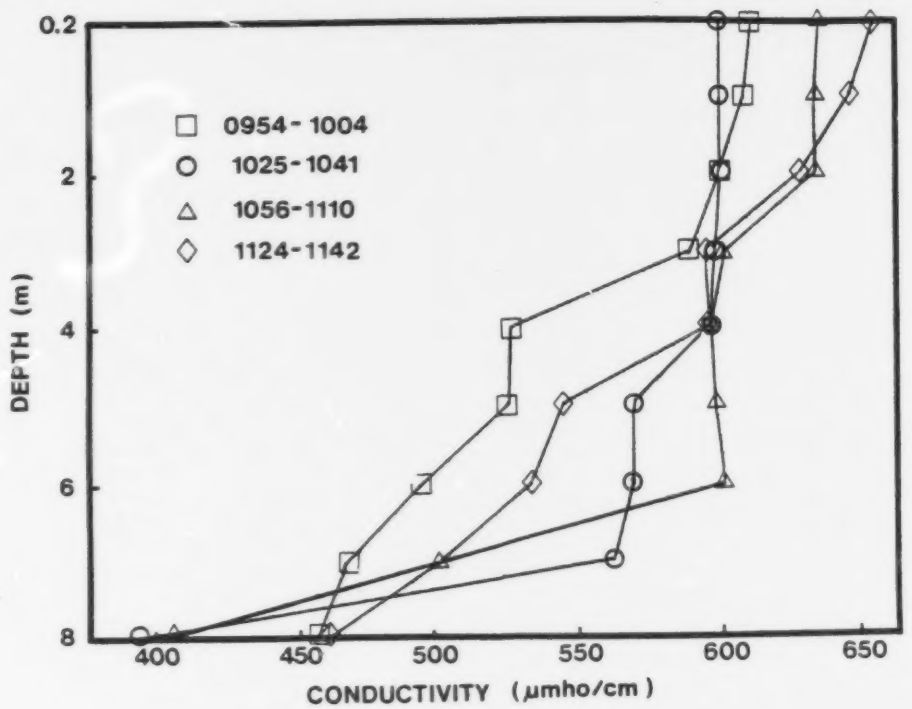


FIG. 3.1e: DEPTH PROFILES OF CONDUCTIVITY IN BURLINGTON SHIP CANAL JUNE 29, 1982

(a) 0954–1142 h



(b) 1354–1512 h

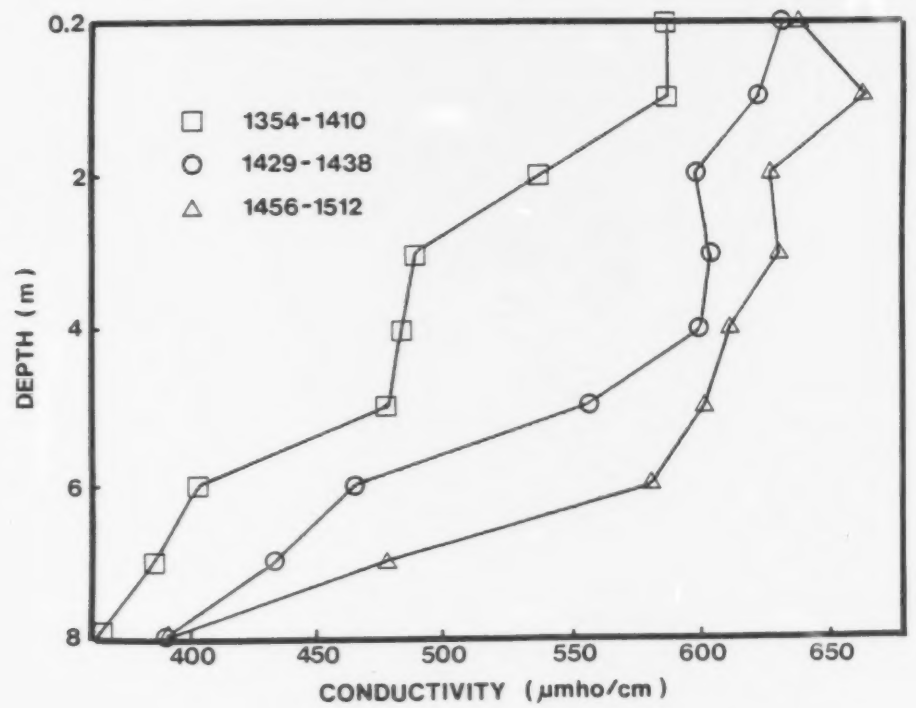


FIG.3.1f : DEPTH PROFILES OF CONDUCTIVITY IN BURLINGTON SHIP CANAL, JUNE 29, 1982

(c) 1532-1712

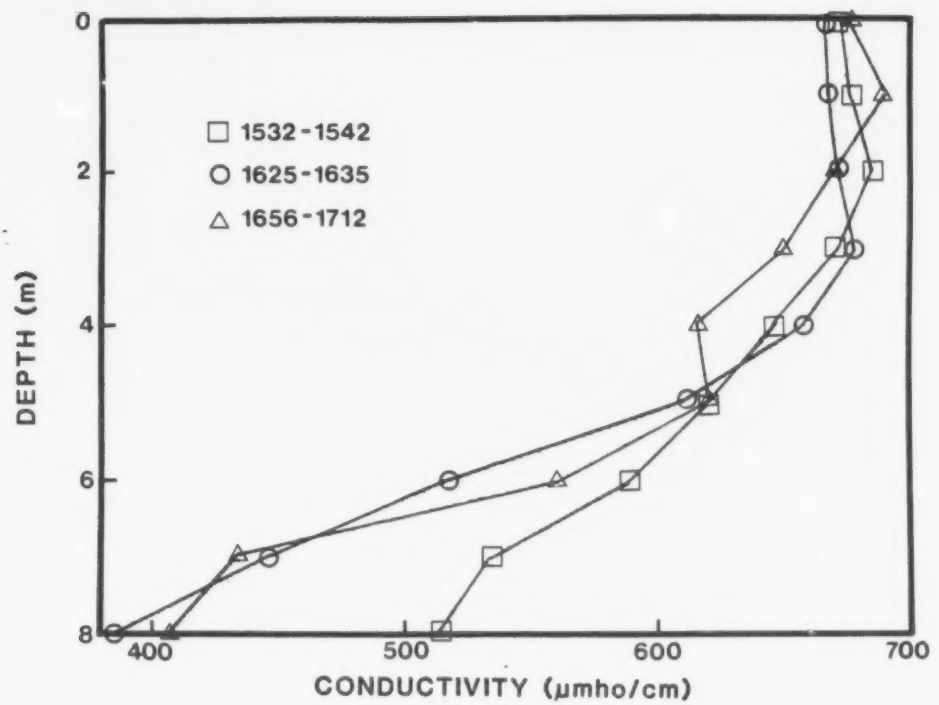
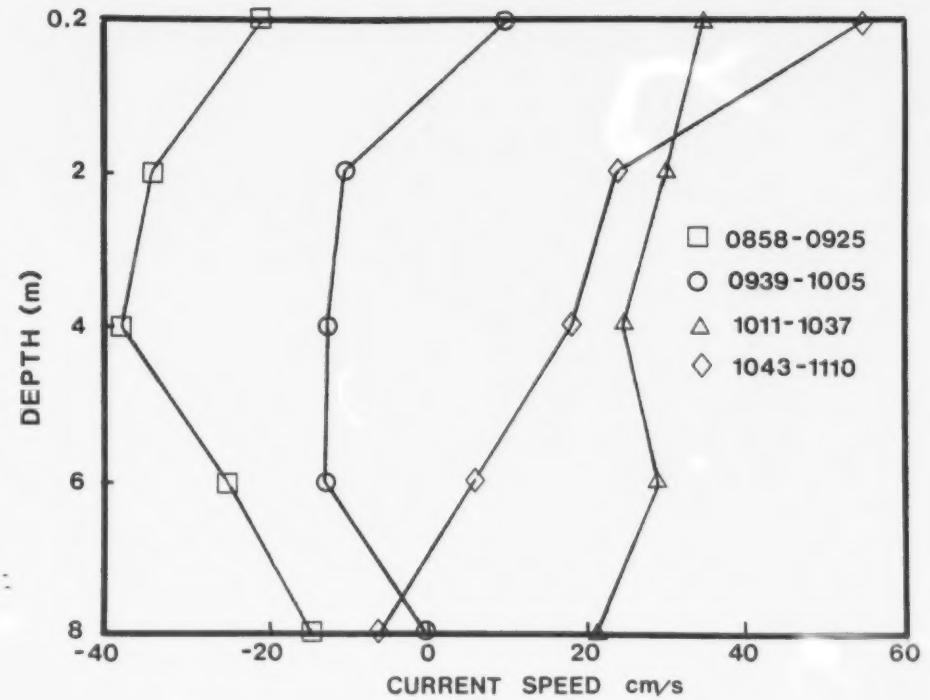


FIG. 3.2a: DEPTH PROFILES OF CURRENTS IN BURLINGTON SHIP CANAL, AUGUST 26, 1982

(a) 0858-1110



(b) 1119-1337

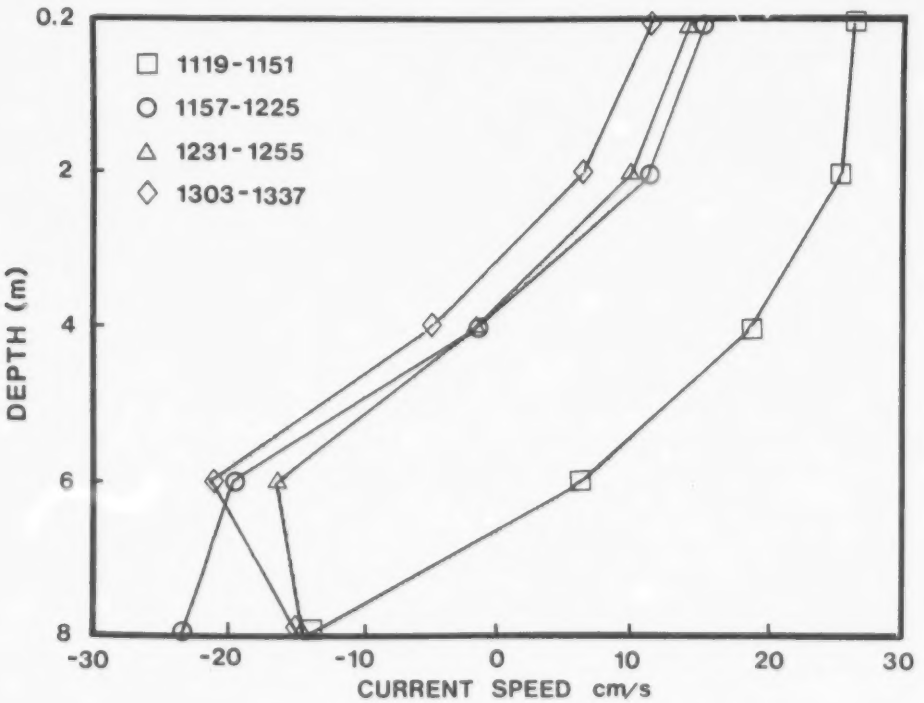
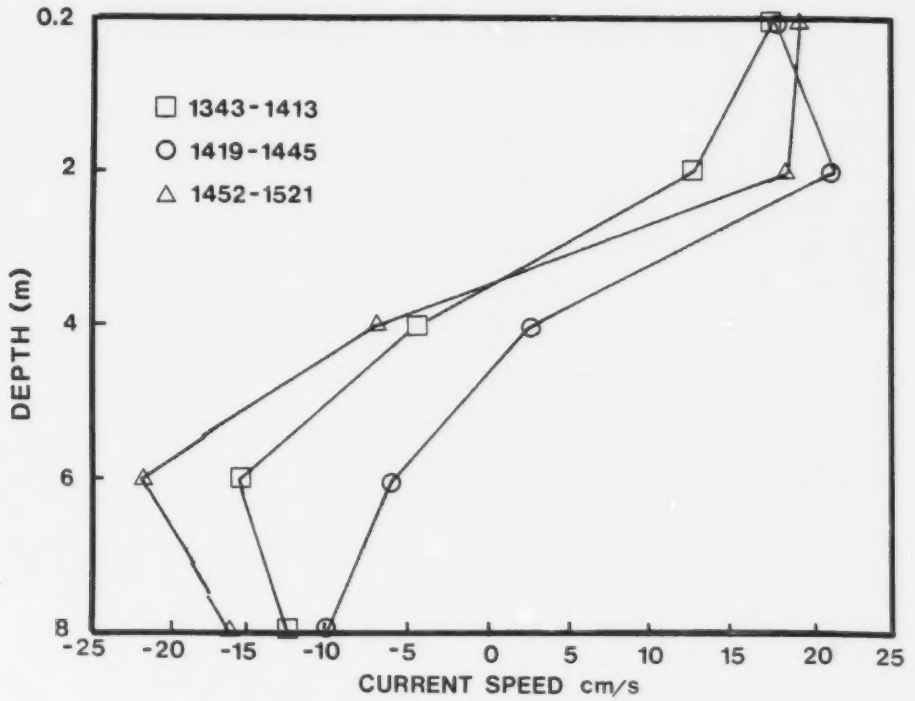


FIG. 3.2b: DEPTH PROFILES OF CURRENTS IN BURLINGTON SHIP CANAL, AUGUST 26, 1982

(c) 1343-1521



(d) 1528-1719

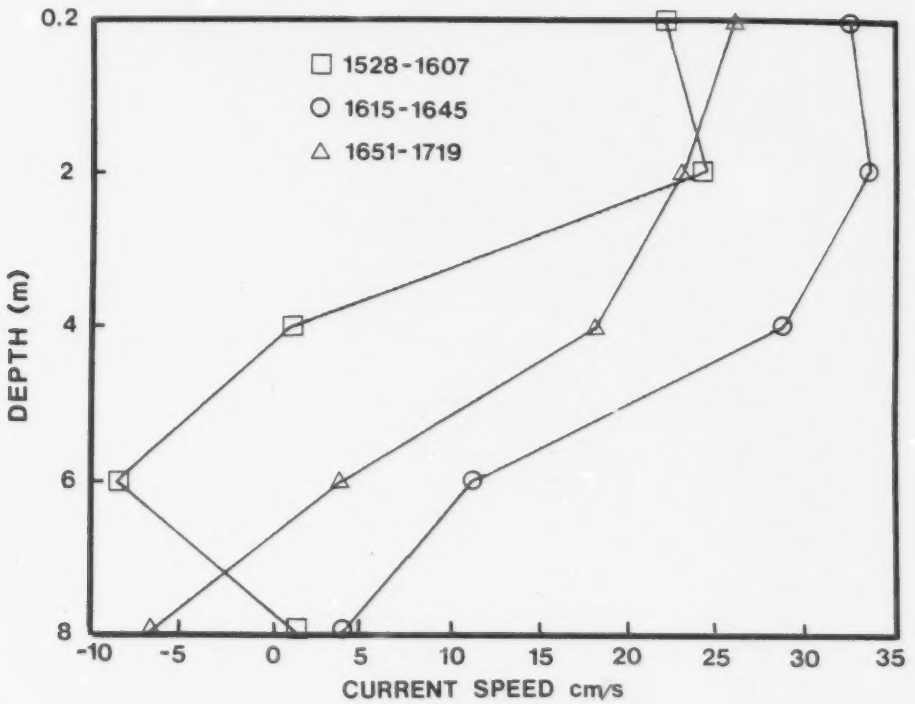
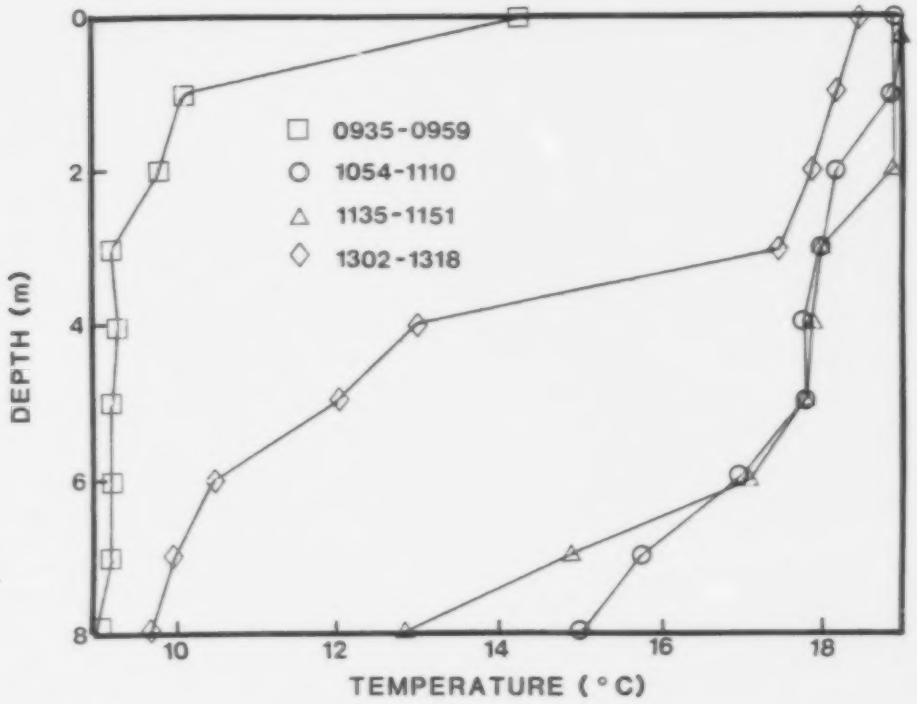


FIG.3.2c : DEPTH PROFILES OF TEMPERATURE IN BURLINGTON SHIP CANAL, AUGUST 26, 1982

(a) 0935-1318



(b) 1350-1510

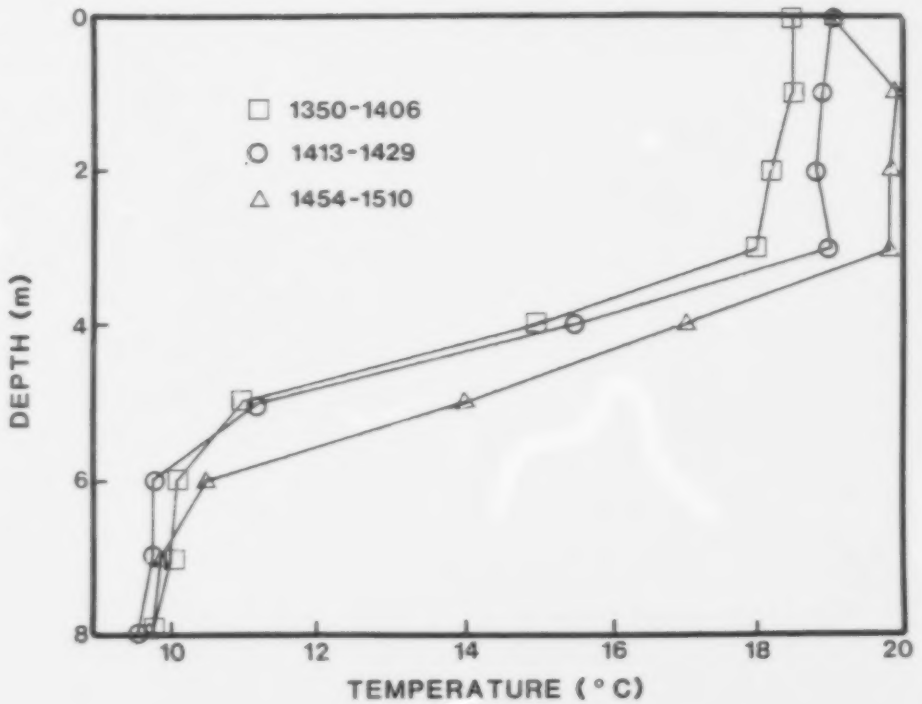


FIG. 3.2d : DEPTH PROFILES OF TEMPERATURE IN BURLINGTON SHIP CANAL, AUGUST 26, 1982

(c) 1515-1713

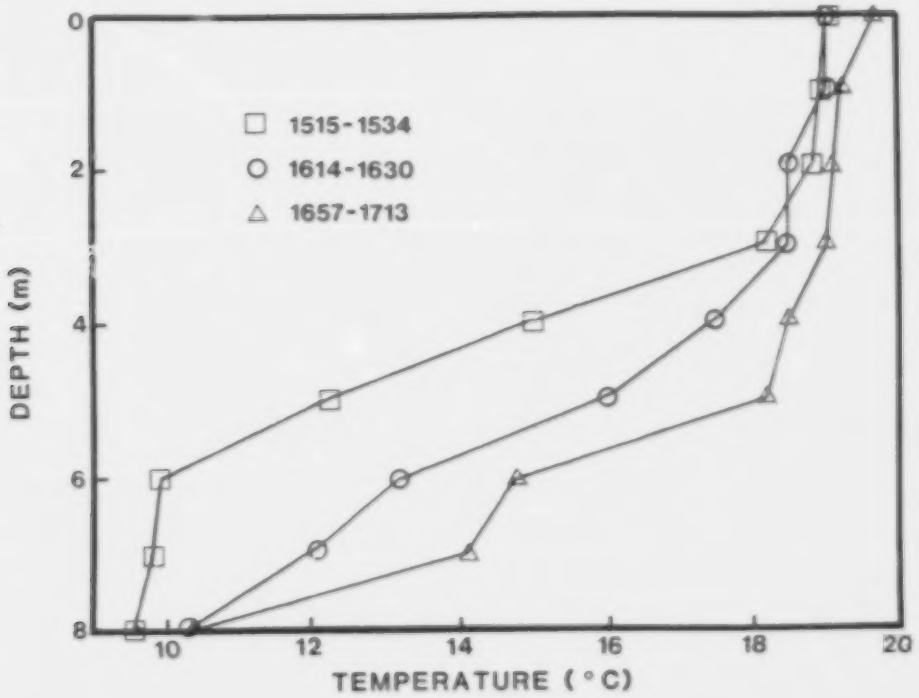
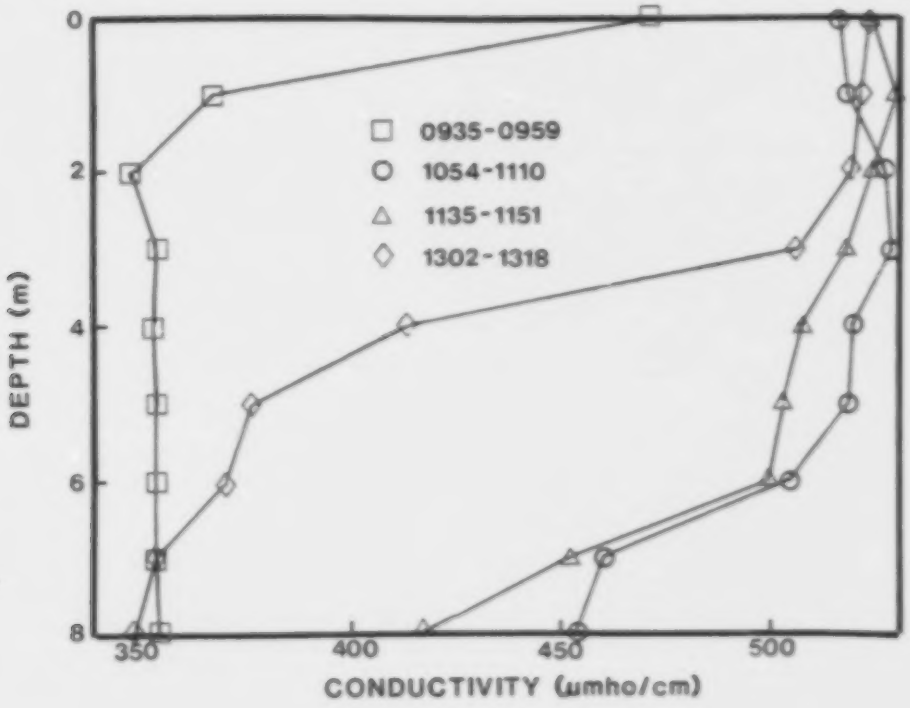


FIG.3.2e : DEPTH PROFILES OF CONDUCTIVITY IN BURLINGTON SHIP CANAL, AUGUST 26, 1982

(a) 0935-1318



(b) 1350-1510

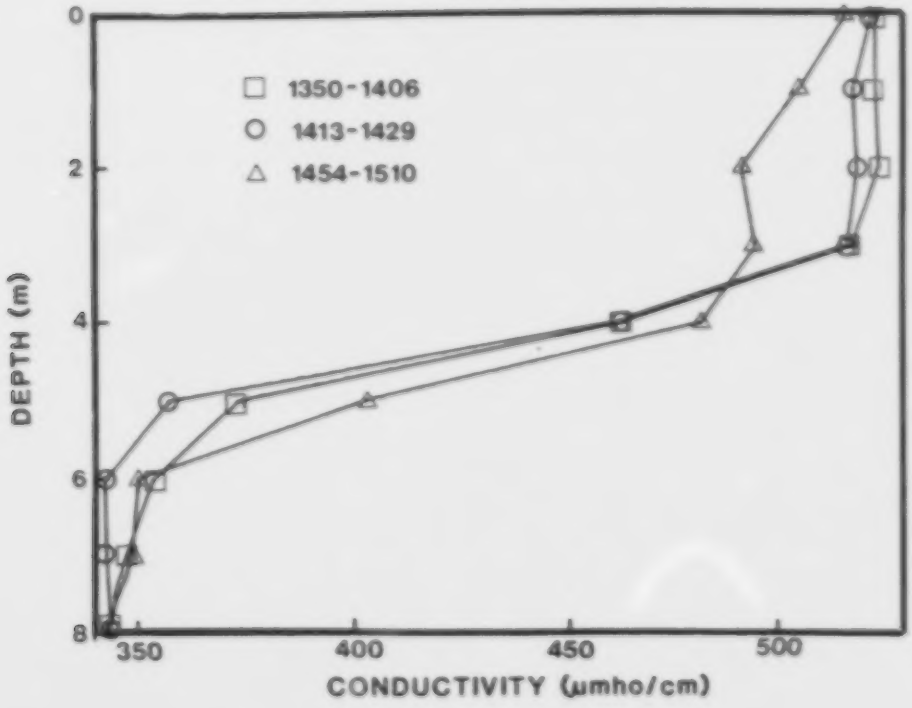


FIG.3.21 : DEPTH PROFILES OF CONDUCTIVITY IN BURLINGTON SHIP CANAL, AUGUST 26, 1982

(c) 1515-1713

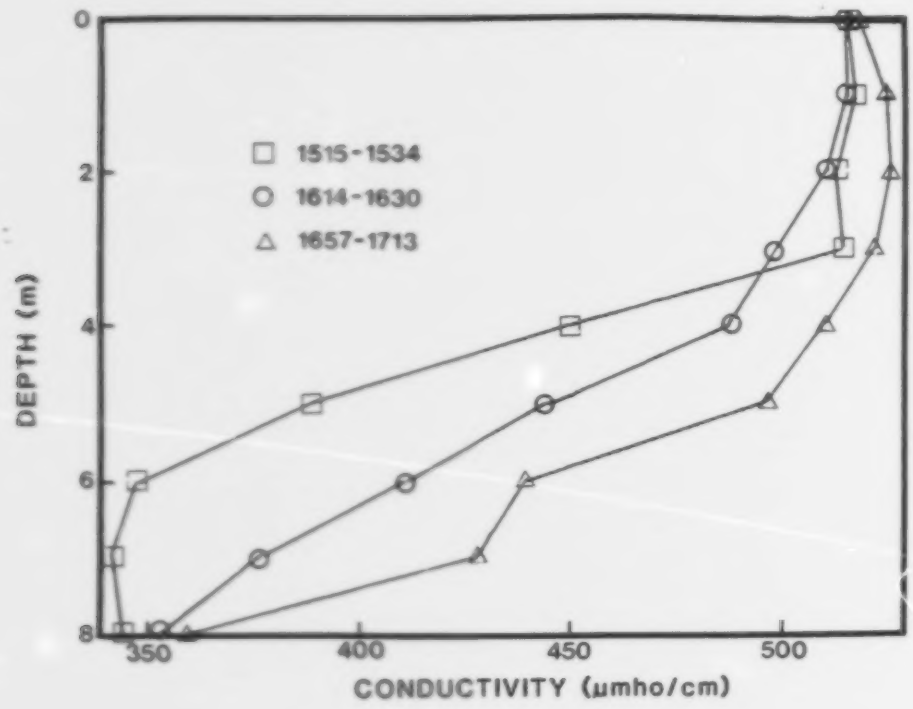
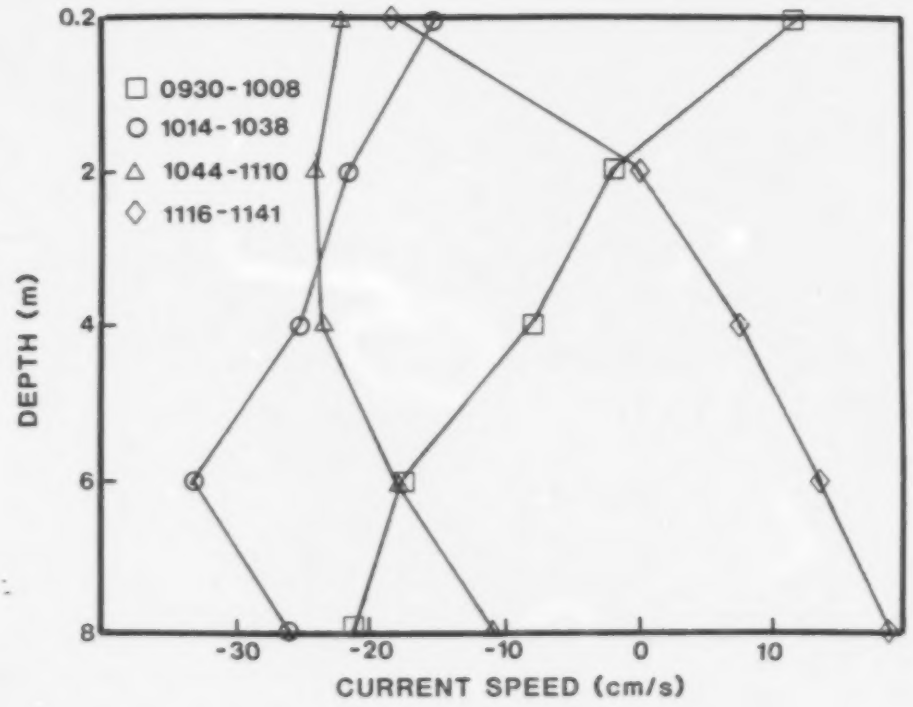


FIG 3.3a : DEPTH PROFILES OF CURRENTS IN BURLINGTON SHIP CANAL, OCTOBER 19, 1982

(a) 0930-1141



(b) 1148-1332

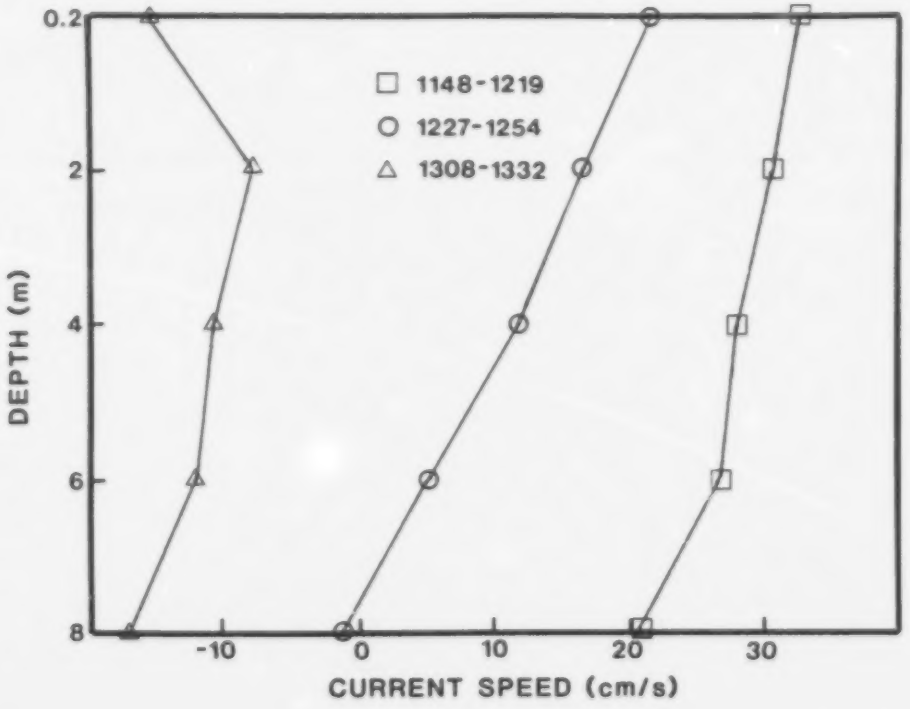


FIG 3.3b: DEPTH PROFILES OF CURRENTS IN BURLINGTON SHIP CANAL, OCTOBER 19, 1982

(c) 1339-1540

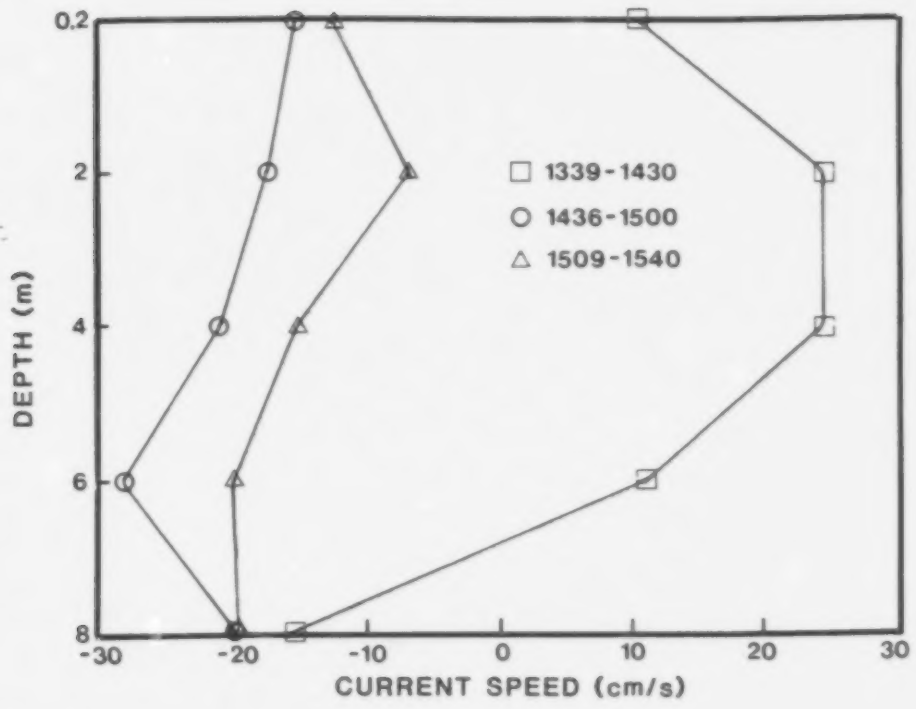
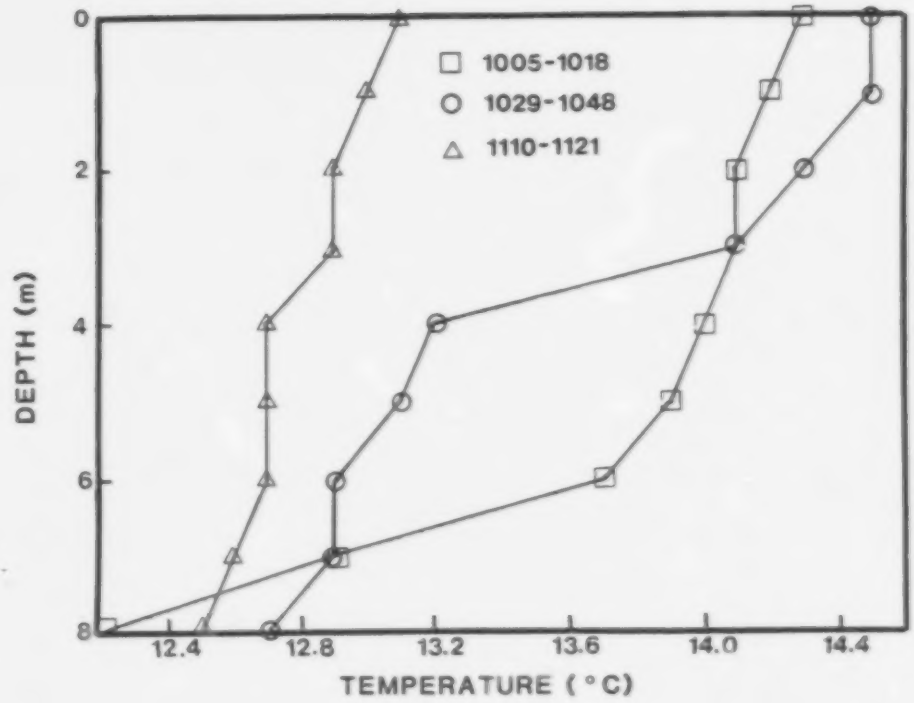


FIG 3.3c : DEPTH PROFILES OF TEMPERATURE IN BURLINGTON SHIP CANAL, OCTOBER 19, 1982

(a) 1005-1121



(b) 1220-1425

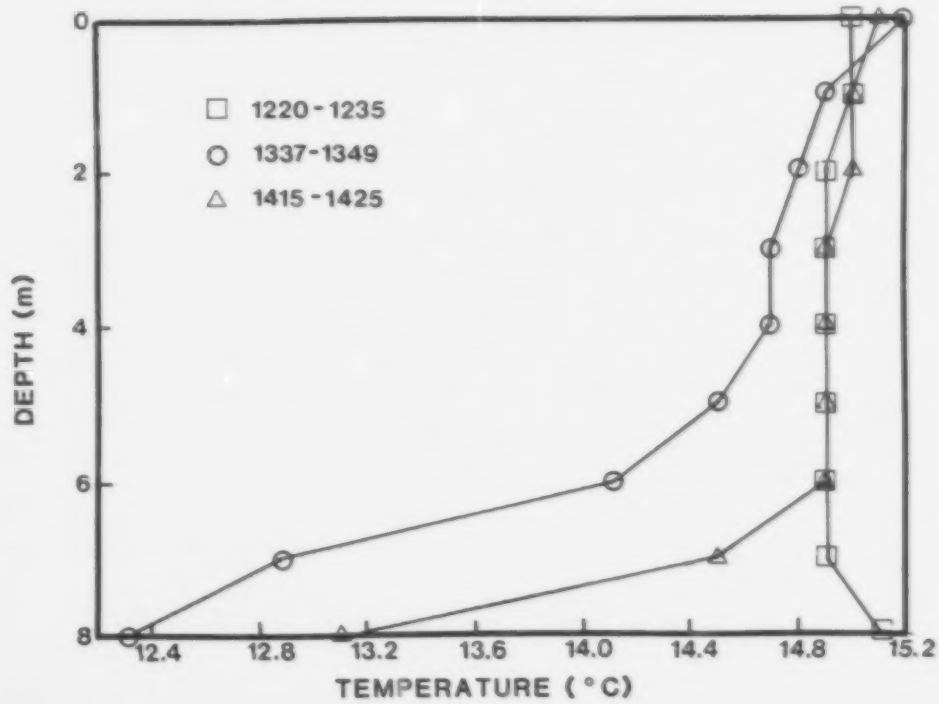


FIG 3.3d : DEPTH PROFILES OF TEMPERATURE IN BURLINGTON SHIP CANAL, OCTOBER 19, 1982

(c) 1432-1533

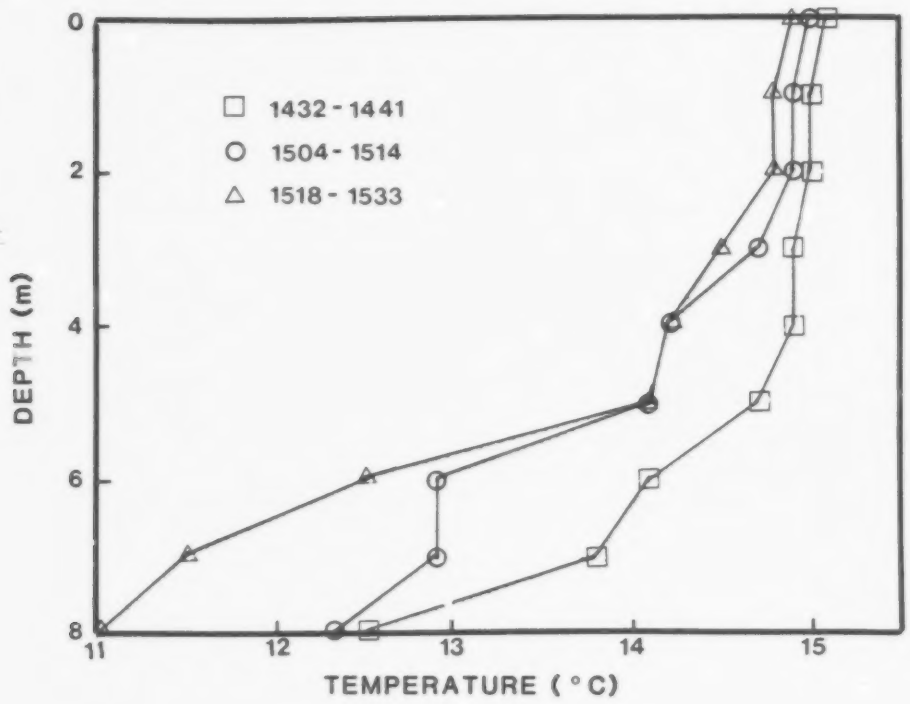
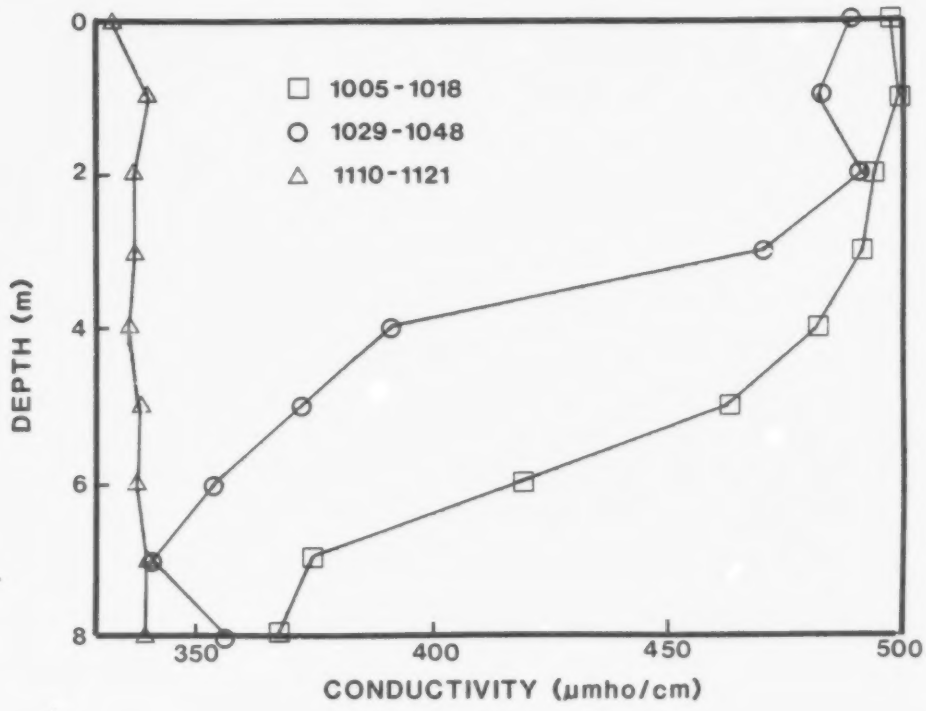


FIG. 3.3e: DEPTH PROFILES OF CONDUCTIVITY IN BURLINGTON SHIP CANAL, OCTOBER 19, 1982

(a) 1005-1121



(b) 1220-1425

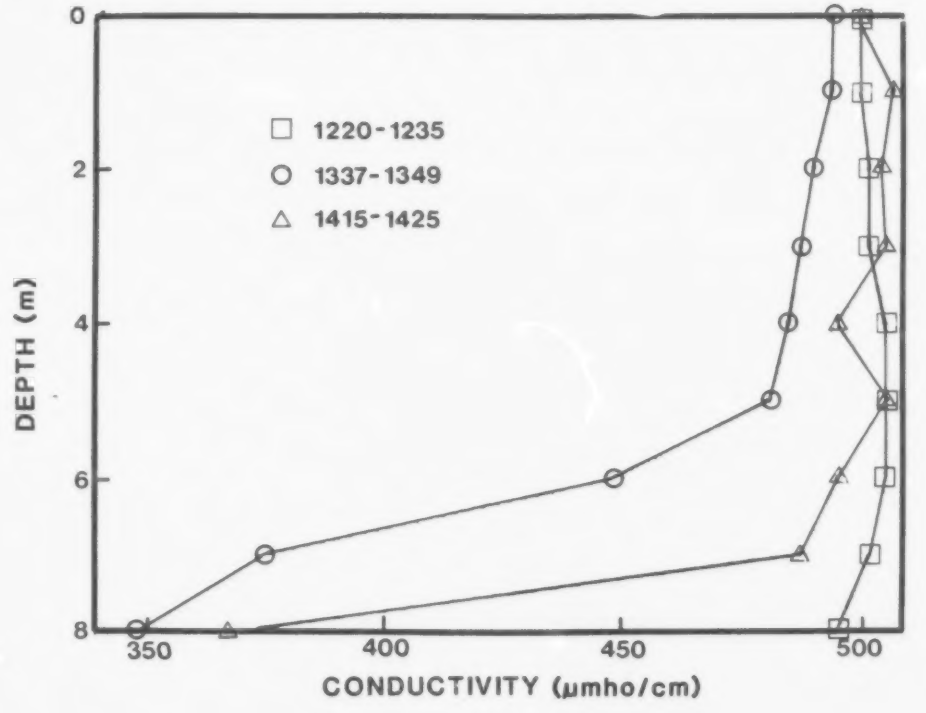


FIG3.3f : DEPTH PROFILES OF CONDUCTIVITY IN BURLINGTON SHIP CANAL, OCTOBER 19, 1982

(c) 1432-1533

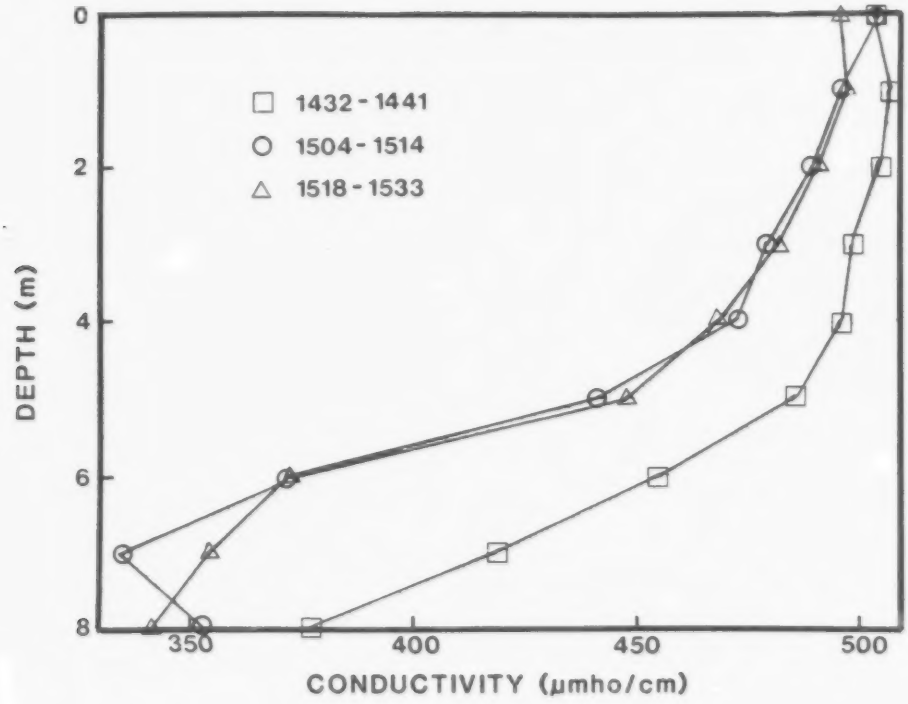
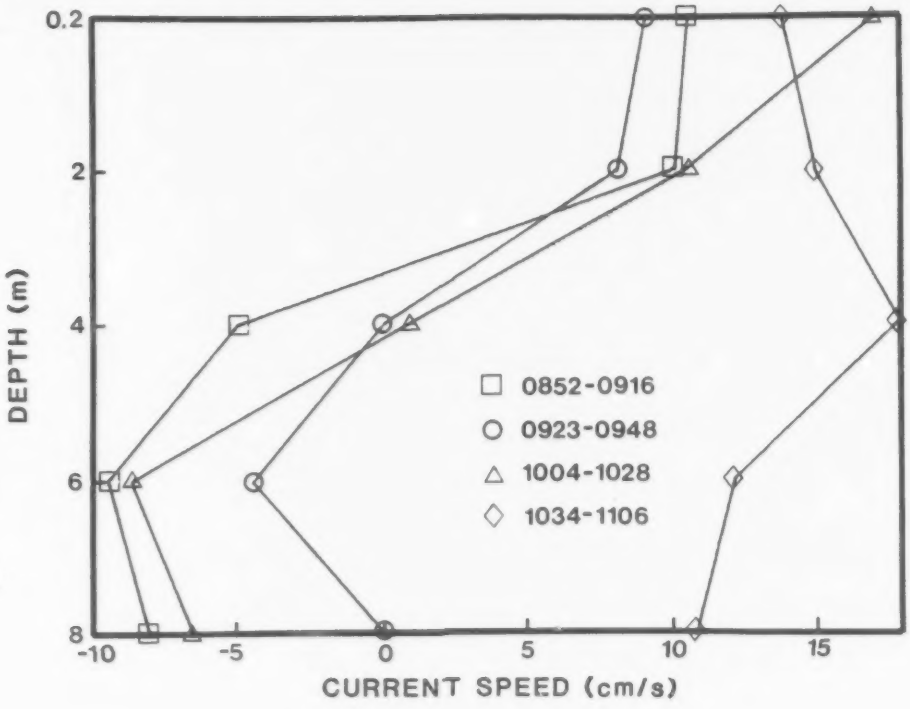


FIG. 3.4a : DEPTH PROFILES OF CURRENTS IN BURLINGTON SHIP CANAL, OCTOBER 22, 1982

(a) 0852-1106



(b) 1113-1306

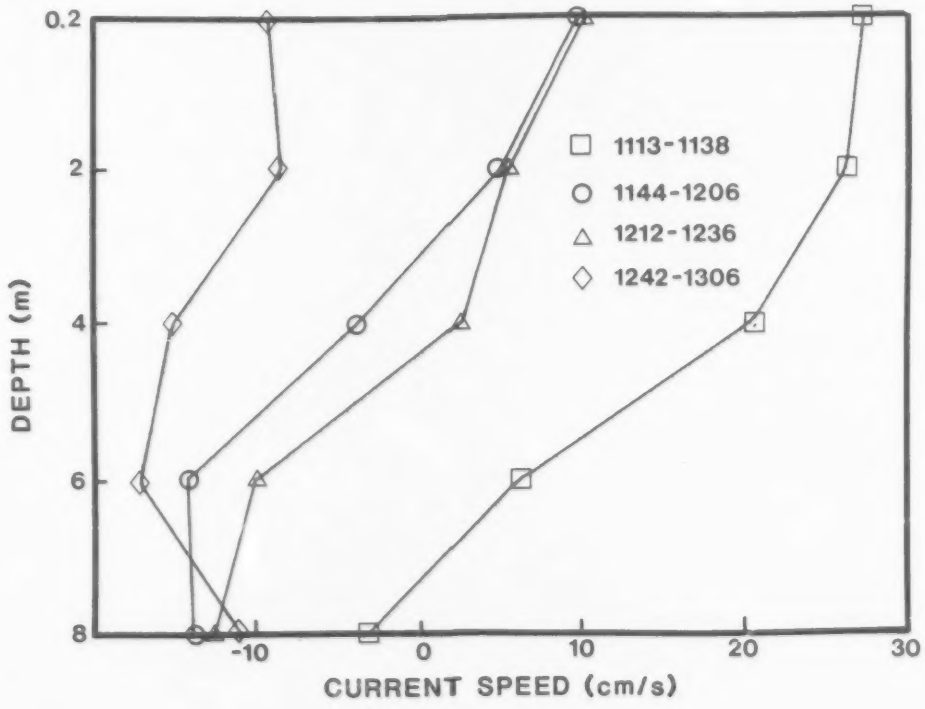


FIG.3.4b : DEPTH PROFILES OF CURRENTS IN BURLINGTON SHIP CANAL, OCTOBER 22, 1982

(c) 1320-1520

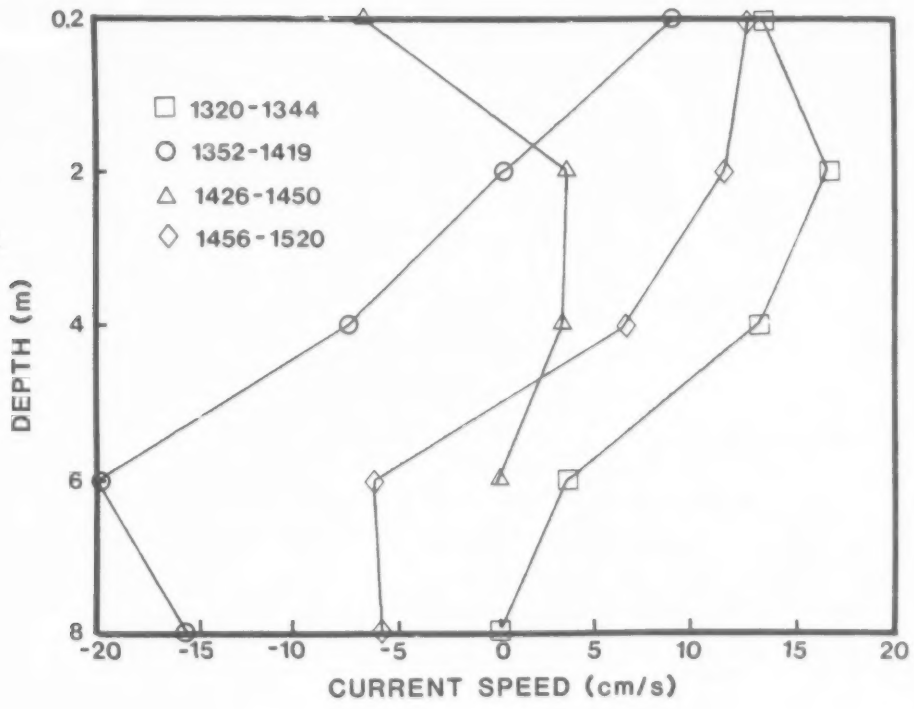
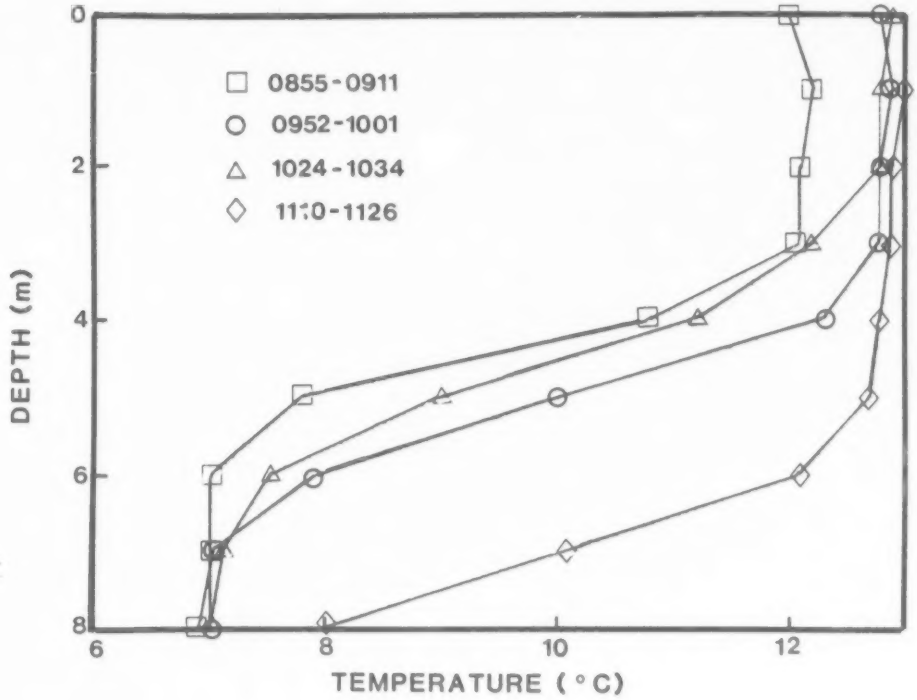


FIG. 3.4c: DEPTH PROFILES OF TEMPERATURE IN BURLINGTON SHIP CANAL, OCTOBER 22, 1982

(a) 0855-1126



(b) 1150-1513

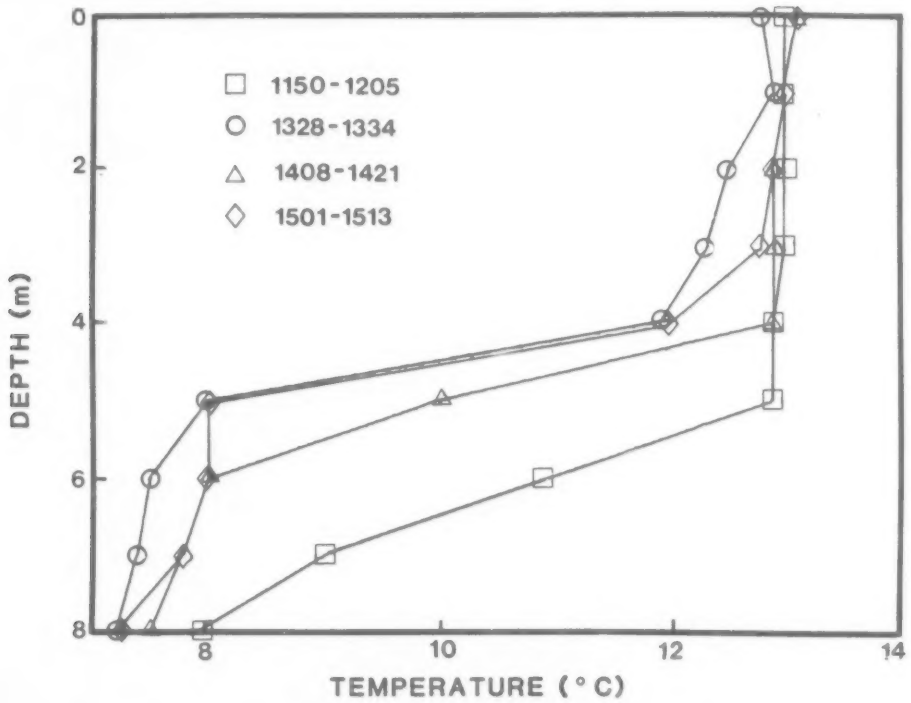
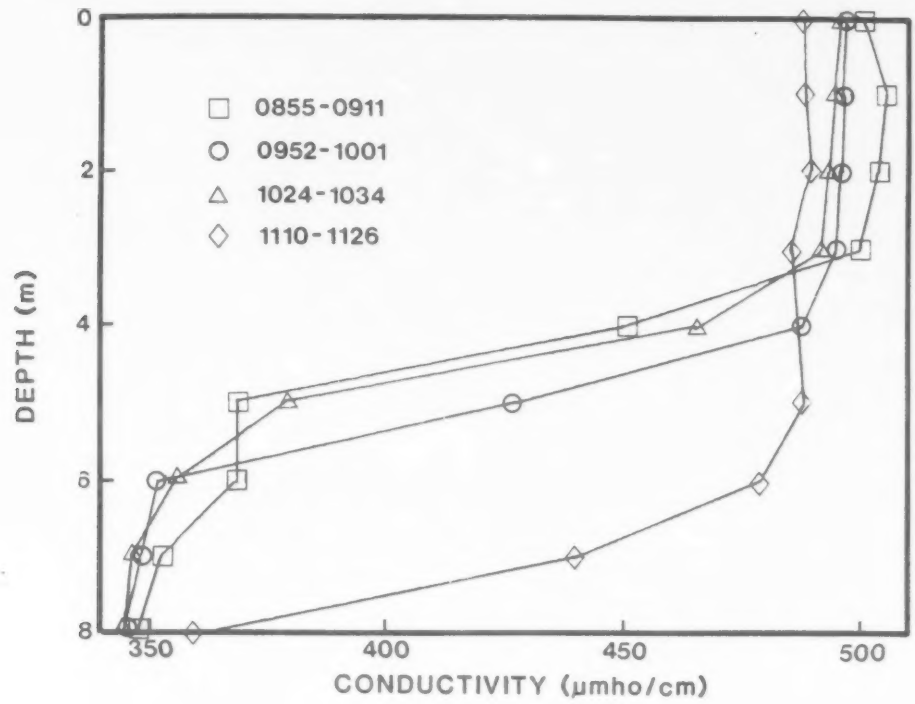


FIG. 3.4d : DEPTH PROFILES OF CONDUCTIVITY IN BURLINGTON SHIP CANAL, OCTOBER 22, 1982

(a) 0855-1126



(b) 1150-1513

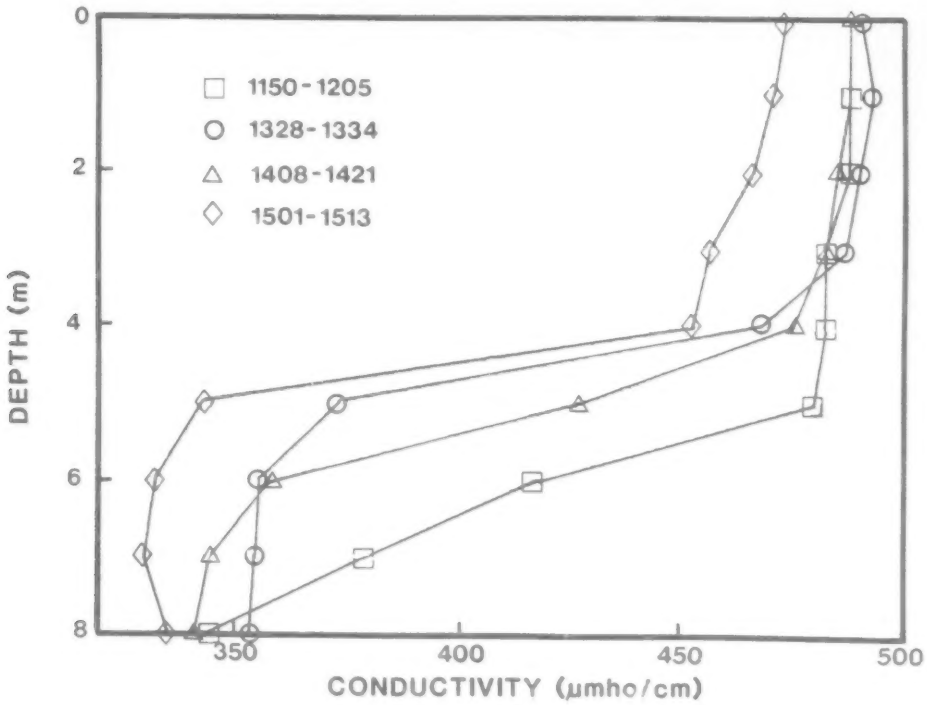


FIG.3.5a : AMMONIA-N CONCENTRATIONS
BURLINGTON SHIP CANAL
AUGUST 26, 1982

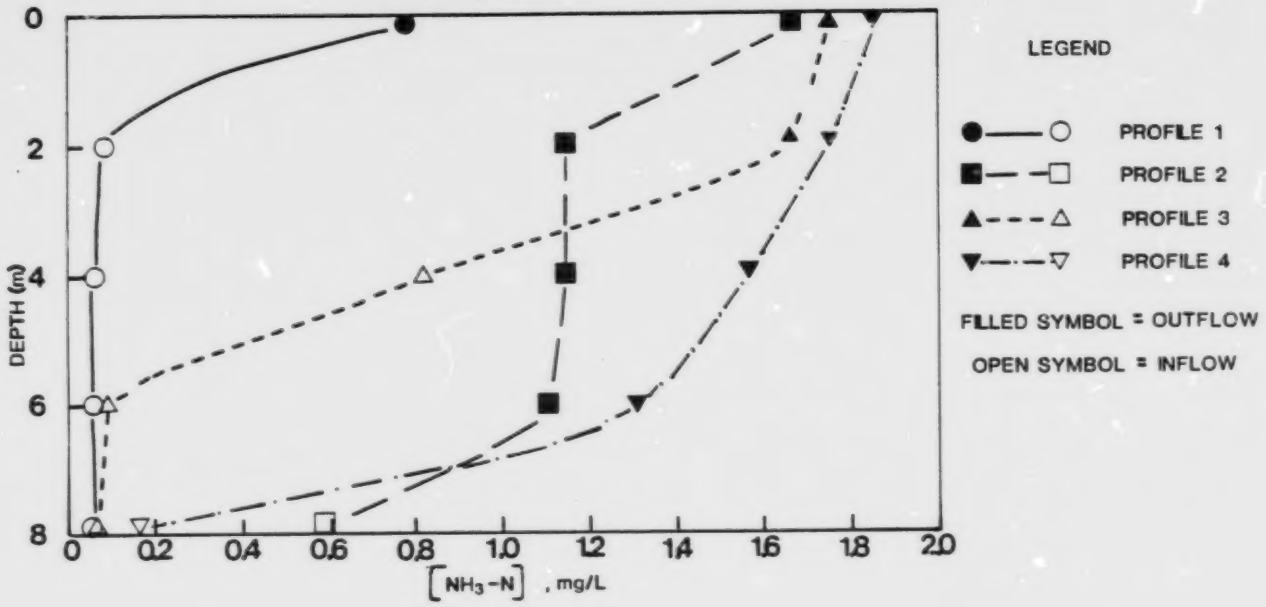


FIG.3.5b: TOTAL PHOSPHORUS CONCENTRATIONS
BURLINGTON SHIP CANAL
AUGUST 26, 1982

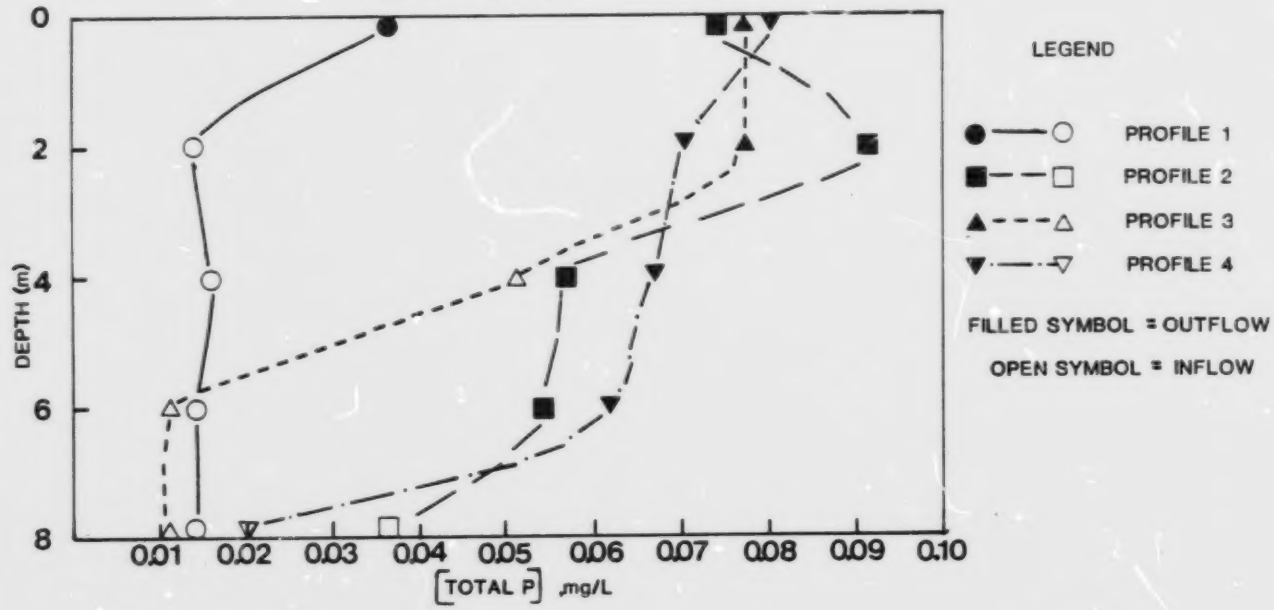


FIG 3.6a AMMONIA-N CONCENTRATIONS
BURLINGTON SHIP CANAL
OCTOBER 19,1982

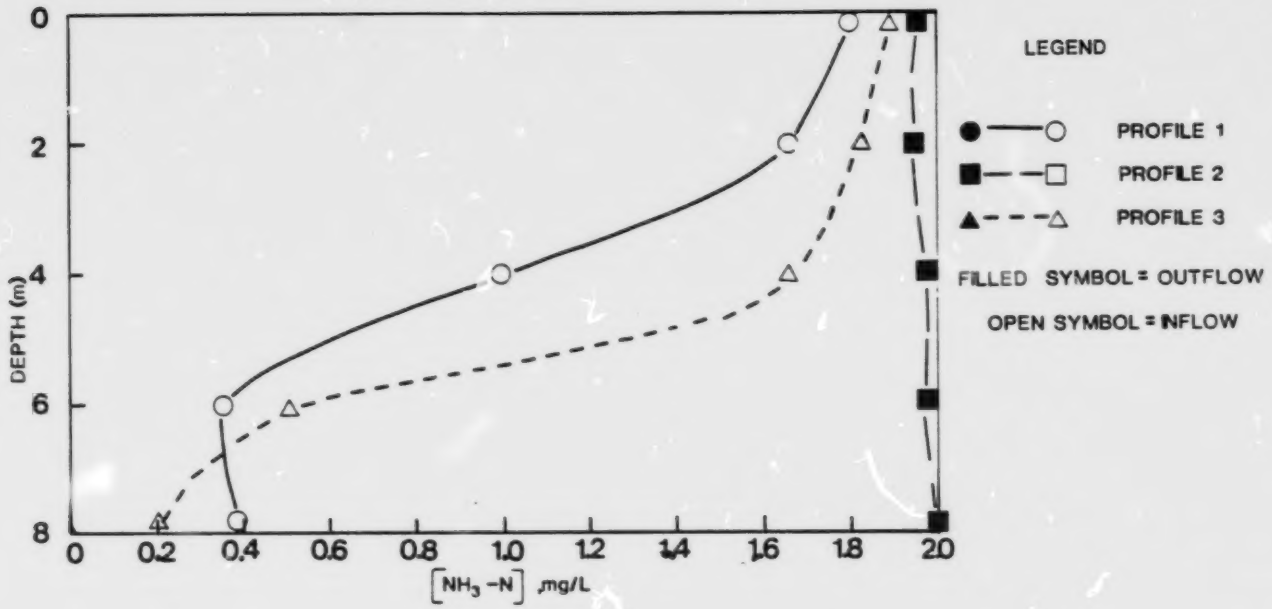
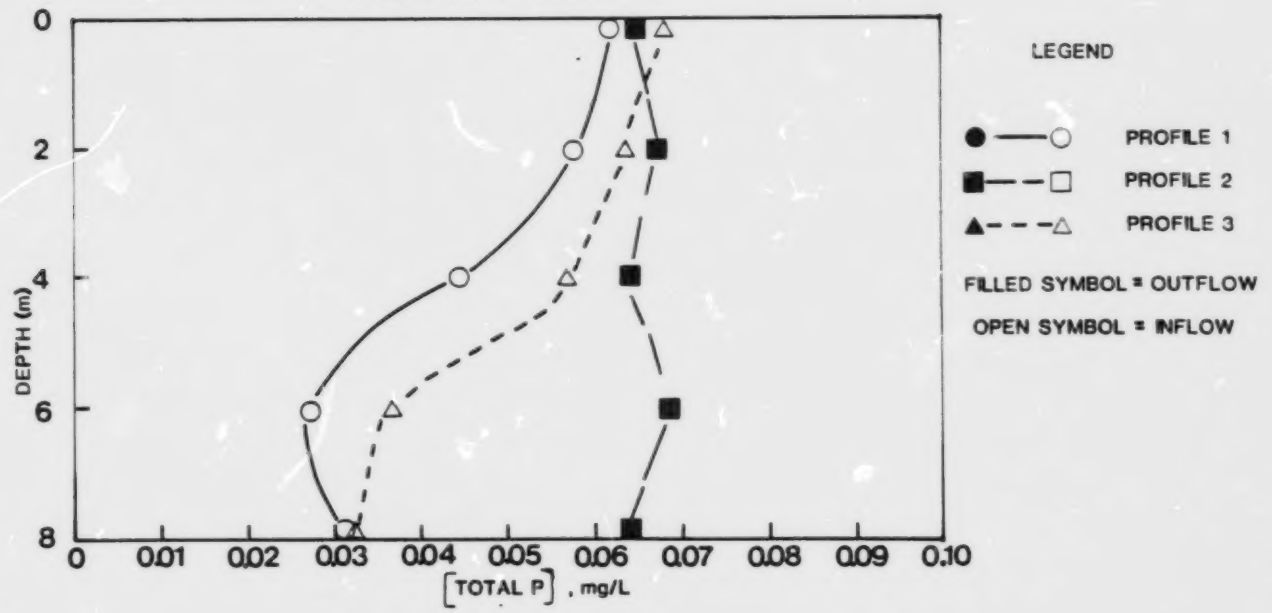


FIG. 3.6b: TOTAL PHOSPHORUS CONCENTRATIONS
BURLINGTON SHIP CANAL
OCTOBER 19, 1982



4.0 PLUME TRACKING IN LAKE ONTARIO

4.1 Introduction

Little data existed with regard to the extent of the plume of Hamilton Harbour water emitted to the western end of Lake Ontario prior to this investigation. Concern has been expressed about the potential of impingement on the Burlington and Hamilton water treament plant intakes, located approximately 4 km northeast and 5 km southeast of the Burlington ship canal, respectively. One of the purposes of this study is to define the extent of the plumes of harbour water emitted to the lake. An attempt is also made to correlate plume configuration with winds and lake currents, and indicate the effect on water quality at the water intakes.

The only previous study of the western end of Lake Ontario was conducted by Matheson (1963), in order to select a location for a new Hamilton water intake. He found average ammonia concentrations above 0.1 mg/L up to 5 km from the canal. The general shape of the contours suggested more transport to the northeast than the southeast. These data were obtained at a time when average harbour ammonia concentrations were more than twice present values.

Matheson (1963), also measured total coliform and synthetic detergents; plumes of these parameters suggested older emissions of harbour water, due to relatively faster biological assimilation of ammonia.

Figure 4.1 shows the study area covered during the plume tracking studies, and its surroundings. The entire western end of Lake Ontario was covered during the plume tracking cruises, generally extending eastward about 4 km from the Burlington ship canal, northward within a few hundred meters of the shore (and close to the Burlington WTP intake), and southward at least 3 km from the canal; on several cruises it extended to the vicinity of the Hamilton WTP intake.

The harbour plume was tracked on 13 separate dates between May and October, 1982. These represent the same dates on which canal measurements (Section 3) were made. Weather conditions on the survey dates are summarized in Table 4.1. Although not all the survey dates are discussed here, those chosen are representative of conditions found on all survey dates. Plume maps for dates not discussed here are found in the Appendix (bound separately).

4.2 Field Procedures

The plume-tracking vessel was equipped with a surface-mounted pump, drawing water from an intake attached to a towed "fish". This enabled a continuous record of temperature, conductivity and fluorescence to be recorded by on-board sensors. Fluorescence was calibrated to give a continuous chlorophyll a record, also measured in the canal boat. Frequent stops were made for sample collection, both within the main plume as indicated by the on-board instruments, and outside, for comparison purposes. At these locations, samples were collected at the surface, 3m (August and October only) and 6m water depths, for analysis of the same parameters measured in the canal samples.

Vessel position was monitored by miniranger, with transponders located at the Riviera Motel in Burlington (Figure 4.1), and the Shell dock at the west end of Oakville. In May, vessel positioning was done by ship's radar, due to malfunction of the miniranger system. This proved to be adequate, but less accurate.

At the start of each cruise day, the plume-tracking vessel proceeded to station 258 in the harbour, where samples were collected at 0.2, 3, 6, 11 m from surface and near-bottom. The vessel then proceeded eastward until it was in line with the canal, and northeasterly through the canal following a straight path past the marker buoy until onboard instruments indicated stable background lake conditions for preferably at least 1 km. At this point, referred to as the "background" point, a series of samples were collected similar to that at station 258. The vessel then returned to a point within 100 m of the east piers of the

Burlington ship canal, and began a series of tracks parallel to the beach strip shore with stops for sample collection at each end of the track nearest shore and additional stops as previously mentioned. On some cruise dates, tracks were also made parallel to the line joining the canal and the marker buoy (i.e. perpendicular to the beach strip shore).

Data from the conductivity, temperature and fluorescence cells on the plume-tracking vessel were recorded digitally on a printed tape at preset intervals (30 s to 1 min in the plume, 2 to 3 min outside); miniranger data were hand-recorded at 1 to 5 minute intervals. As with the canal study, these data were later transcribed onto coding forms and keypunched for computer analysis.

4.3 Data Analysis Procedures

As described for the canal data in Section 3.3, conductivity was corrected to 25°C, and chlorophyll was calculated by multiple regression against fluorescence, temperature and time. Regression results are given in Table 4.2. Although fluorescence explains the largest portion of variance, temperature is also significant on most dates except in October. This may be due to reduced photosynthesis in colder lake waters. In October, the thermocline was deeper and far less temperature variation was observed.

Sampling times at the datalogger were corrected for hose residence time and the speed of the datalogger clock. The hose residence time was about 30 seconds and was large enough for the vessel to move a significant distance, particularly near the canal mouth. Only on one date did the speed of the datalogger clock vary by more than 3 percent from true time; the error is due to lack of 60-cycle frequency stabilization on the AC currents generated by the on-board gasoline generator.

Miniranger data (distances in metres between the vessel and each of two transponders) were converted into X- and Y coordinates on an axis system based on the UTM grid. The coordinates were verified by checking against the times of vessel passage by the canal piers and marker buoy. These showed that the miniranger system performed adequately at all times within the lake with only minor corrections (<20 m) sometimes needed to match results to field observations of passage by the canal piers and marker buoy. Within the harbour, the miniranger results were not satisfactory due to the transponder locations used; this was not important in fulfilling the aims of the study. Data for May (ship's radar) were plotted onto hydrographic charts, digitized and converted by computer to the same UTM grid system.

The miniranger data were then interpolated to coordinates representative of boat positions when water entered the intake hose for all datalogger readings. This provided a dataset containing time, Xand Y- location coordinates, temperature, conductivity and chlorophyll which was used for contour plotting of all parameters. Chemical samples whose coordinates were obtained by correlating field notes and sampling times with the above output were also included in the data set.

As with the canal data (Section 3.3), the computer routines used to accomplish the above tasks are described in more detail by Senyshyn (1984).

4.4 Results and Discussion of Conductivity and Chlorophyll Plumes

As the nearshore area of western Lake Ontario is very dynamic, the appearance of the harbour plume changed considerably from day to day, and even from hour to hour during the individual cruises. Similar to the canal data (Section 3), several dates will be discussed in some detail.

All data were transformed into nondimensional values before plotting, for ease of indicating the proportion of lake and harbour water at any given point. As well, this method removes the effect of day-to-day

variations in water chemistry at the reference locations (harbour station 258 and lake "background"). The formula used is:

$$X_R = \frac{(X - X_B)}{(X_{258} - X_B)}$$

where X_R = reduced conductivity or chlorophyll value at any location

X = conductivity or chlorophyll at any location

X_{258} = station 258 value (Figure 4.1)

X_B = "background" value (reference point at least 3 km from canal piers along line from canal to marker buoy projected outward)

In the discussions that follow it should be noted that the phrase " ...% above background" refers to the relative elevation above background, i.e. the quantity 100 X_R. This enables a comparison of percentage increases in parameter concentrations at plume tracking stations over "background" (control) versus the difference between "background" and station 258 (worst case) which is considered to be 100%. Presence of a plume would be indicated by parameter concentrations >10% above "background". "Background" and station 258 values are summarized for each day in Table 4.3. Because of the dynamic nature of the harbour plume, some averaging of data obtained on each day was necessary, and only two contours were plotted for each day and parameter. Contour plots are given in Figures 4.2 - 4.7. Contour plots for dates not considered here are given in the Appendix (bound separately; available on request from the Great Lakes Section, Water Resources Branch).

4.4.1 Plume Tracking - June 29

As a total of 7 h of plume tracking was performed on this day, the data were broken down into two portions, representing the first five (Figure 4.2a-b) and last two (Figure 4.2c-d) hours respectively. Wind direction was variable with an average speed of 9.4 km/hr (Table 4.1); however, these are measured at the Hamilton airport and may not be representative of conditions on the lake. Bridge current data

(Section 3.4) showed alternating inflows and outflows of water at the canal. The initial track to the background location and return to the canal piers showed several patches of water with increased conductivity and chlorophyll within the first 2 km from the piers. These are shown as the 372 umho/cm and 12 ug/L contours in Figures 4.2a-b, respectively. They are believed to relate to the several outflows which were observed at the bridge during the early part of the profiling (or prior to commencement of profiling). However, no confirmation of this hypothesis is possible without a detailed grid of current meters and/or a time-dependent numerical model.

Multiple north-south tracks showed that the plume reached at least 1.7 km northeast of the canal (330 umho/cm; 20% elevation of conductivity above background of 290 umho/cm), but not to a track 2.3 km from the canal (which was the approximate limit during the track to the background). The plume was directed somewhat north of the line joining the canal piers to the marker buoy. Later in the day, east-west tracks (Figure 4.2c-d) confirmed this plume orientation, and again showed pulses of higher conductivity water near the canal.

The chlorophyll plume was considerably larger than the conductivity plume and directed more to the north. Early in the day, the highest chlorophyll values were found near the shore, to the north of the canal. A lower chlorophyll area (<9 ug/L) was found immediately to the east. Later in the day, the areas of |9 ug/L (40% elevation above background of 3.6 ug/L) appeared to have broken into several distinct patches. However, these phenomena may have resulted as much from temporal variations of in-lake photosynthesis as from true spatial effects.

4.4.2 Plume Tracking - June 30

On June 30, water flowed outward from the canal almost continuously at the surface, while outflows alternated with inflows at deeper depths. Plume tracking results appear to be coincident with winds from the north-west averaging 16.7 km/hr (Table 4.1). The plumes are shown in Figures 4.3a-b. Again, a zone of higher conductivity was found about 1 km from the piers, but less irregularity was observed compared to June 29, perhaps because of the continuous outflow.

By contrast to the previous day, the plume on June 30 was directed more to the south of the centerline from the canal to the marker buoy. In fact, when tracking very close to shore, the boat immediately left the plume when going north, but encountered plume conditions 1.1 km south of the piers. North-south and east-west tracks further from shore found the highest concentration about 0.5 km south of the pier-to-buoy line, although elevated conductivity did occur both north and south of the line.

Again, on June 30, the chlorophyll plume was considerably larger than the conductivity plume. Chlorophyll values over 7 ug/L (40% elevated above background) were found as far as 4 km east, 1.8 km southeast and 1.5 km north of the canal. The north-south tracks did not cover an area far enough east for full definition of the chlorophyll plume (see the dotted line on Fig. 4.3b). This result appears to parallel the water chemistry results (Section 4.4), which indicate plume conditions at points farther removed from the canal than are indicated by conductivity results.

4.4.3 Plume Tracking - August 24 - 28

On August 24, flow through the canal was stratified for the entire day, with outflow at the surface to speeds as high as 37 cm/s, and inflow below depths of 3 to 6m. Combined with the thermal stratification in the lake, this outflow produced the largest conductivity plume of any survey day. Winds averaged 8.1 km/hr from a WSW direction, measured hourly throughout the day. The plumes are shown in Figures 4.4a-b. On the initial track to background, the boat travelled 6.4 km from the canal before reliably constant conditions were encountered; conductivity values 10% above background were found as far as 4.3 km from the canal, and 20% above background at 3.4 km from the canal (383 umho/cm).

At a distance of 1 to 2 km from the canal, the plume was almost symmetrical, but was directed somewhat northward at greater distances. The most distant north-south track did not fully define the area of 20% or more above background (dotted line on Figure 4.4a-b). The dynamic nature of the plume was revealed by one track from the marker buoy

(Fig. 4.1) inward to just north of the canal, and northward near the shore which showed conductivity and chlorophyll values within 10% of background for almost the entire interval from 0.8 km from the canal inward and northward. Later in the day, in the same area along the buoy-to-canal line, the conductivity was more than 40% above background (421 umho/cm).

Chlorophyll results on August 24 indicated a plume area very similar to that of conductivity, contrasting the larger chlorophyll plumes found in June.

By contrast to August 24, on August 26 and 28, the plume area was far smaller, with conductivity values 20% above background extending only about 1.2 km from the canal on August 26, and 2 km on August 28. Plumes for August 26 are shown in Figures 4.5. A small patch of elevated conductivity was observed about 2.5 km from the canal on one track August 26, but not on a later track on the same day. Winds averaged 12.2 km/hr from a SW direction for this period. The chlorophyll plume was similar in size to the conductivity plume in August 26 and slightly larger on August 28, where it extended about 3 km eastward and 2 km southeastward from the canal piers. These differences may be due in part to WNW prevailing winds at 15.8 km/hr measured on the 28th.

4.4.4 Plume Tracking - October 22-23

As stated in Section 2.4, stratified flow was observed in the canal for most of October 22, contrasting to the plug flow generally observed on October 19 and 23. Although far smaller than the August 24 plume, the October 22 plume (Figure 4.6) was larger than that observed on October 19, perhaps because of the stratified flow on October 22 (Section 3.4.3). Relatively calm winds averaging 4.3 km/hr from the north-west may have optimized stratified conditions through minimal mixing. The plume was directed more to the south (1.3 km) than to the north (0.6 km). To the east, a strong plume (conductivity 40 to 60% above background) was found 0.4 km from the canal, but no plume (less than 10% above background) was observed at 0.8 km from the canal. The chlorophyll plume was slightly smaller than the conductivity plume.

Later in the day, the plume expanded eastward to 0.8 km from the canal (not shown in Figure 4.6a), but still later, the plume retreated again to an area similar to that shown.

The most severe southward orientation of any survey day was found on October 23 (Figure 4.7). No plume was detected along or just north of the canal-buoy line (at a time of observed canal inflow). Later, under conditions of outflow at the canal, the primary plume extended about 0.8 km to the southeast of the piers. However, remnants of other plumes were detected at more distant points extending southeastward to the vicinity of the Hamilton water treatment plant intake. Winds throughout this day averaged 6.8 km/hr from a WNW direction. Conductivity values of 20% above background (371 umho/cm) were found as far as 3.5 km southeast of the piers, and 10% above background to 5 km from the piers (very close to the northern pair of intakes). The area of 10 to 25% above background appeared to be confined to a zone extending about 0.5 to 1.5 km from shore. This indicated a definite potential for impingement on the Hamilton water treatment plant intake on this date. The chlorophyll plume was highly irregular and variable with time; it was impossible to show the true range of variation in Figure 4.7b.

4.5 Results and Discussion of Lake Chemistry Depth Dependence

On each survey day, grab samples for water chemistry were collected at harbour station 258, a lake background station (the maximum distance eastward from the canal), one station at each of the north and south end of the initial track closest to shore, and 3 to 7 other locations within the plume, these latter locations being selected according to conductivity and fluorescence data on board the survey vessel. At station 258 and the background location, samples were generally obtained at 0.2, 3, 6, 11 and 20 m water depths. At the other locations, samples were obtained at 0.2 and 6 m in May and June, and 0.2, 3 and 6 m in August and October. These samples were analyzed for the same parameters as the canal samples (Section 3.5).

Water chemistry results for samples collected at station 258 are given in Table 4.4. For the most part, these data are not significantly

different from those collected in 1975-80 (MOE 1985). This is especially true considering the seasonal cycles of parameters such as N and P as observed in the harbour. In 1982, a comprehensive survey of heavy metals and trace organics was conducted in the harbour; these data are discussed elsewhere (Poulton 1986).

Average parameter values for samples collected at the background locations are given in Table 4.5. Although these were to have been collected at locations distant enough from the canal to represent ambient lake conditions, several shortcomings subsequently became apparent: (a) On May 20, conductivity results suggested relatively constant conditions from 0.3 to 2.5 km from the canal; "background" samples were thus taken within this zone. However, surface concentrations of chloride and most nutrients were significantly higher than deeper water concentrations at this location. They were also higher than those observed close to shore at points about 2 km north and south of the canal. It was decided that background was not reached on this date, and these samples were excluded from the statistics. (b) On June 30, the sampling vessel stopped to collect samples 2.8 km from the piers and then proceeded another 2.1 km further eastward, during which time a small drop in conductivity and a considerable drop in fluoresence occurred. No samples were taken from this latter location for any parameter other than chlorophyll, however. Data for this date were also excluded. (c) On June 28, the conductivity unexpectedly increased when the sample intake was lowered to 3m. Results for most parameters at this depth were significantly higher than average background values for this depth, and they were therefore not included in the statistics. This represents the only evidence for a sinking plume obtained during the survey.

The background statistics were compared to the results of 1976-79 spring nearshore averages for water quality zones representing non-impacted areas (MOE 1980; Table 4.6). No significant differences were found, indicating that these statistics represented true "background" conditions, i.e. no detectable influence from Hamilton Harbour or any other pollution source.

Figures 4.8 - 4.21 illustrate depth dependence of water chemistry within the plume area. The results will be discussed by individual parameter, with emphasis on the dates discussed in detail in Section 4.3.

4.5.1 Conductivity

Although conductivity is discussed in detail in Section 4.3, a brief mention is made here with regard to depth dependence, which was not discussed previously. As shown for June 30 (Figure 4.9) and August 24 (Figure 4.10), high conductivity values are nearly always confined to the surface, with results at 3 and 6 m only slightly above background values. As mentioned previously, the result of June 28 (Figure 4.8) is an exception, with a maximum value for conductivity being observed at 3 m depth at the "background" point. The result for 6 m was also slightly elevated, compared to surface and 9 m. Unfortunately, no measurement was made at 3 m at other locations on this date. This would have permitted tracing of the apparent sinking plume observed at this location.

4.5.2 Chloride

This parameter was chosen for monitoring, as it represents a larger proportion of total major ions in the harbour water, relative to the lake water (MOE 1977) and is thus a sensitive indicator of the presence of a plume. Again, results for June 30 (Figure 4.11) show the plume to be largely confined to the surface, although some elevation of chloride occurred at 6 m depth at point E, about 1.5 km from the canal. This point, on the edge of the conductivity plume (384 umho/cm contour in Figure 4.3a), and point A, about 1 km beyond the contour, show that chloride is at least as sensitive as conductivity in defining the plume area (point A has approximately 10% elevation of conductivity above background). These points, however, are well within the chlorophyll plume (Figure 4.3b).

On August 24, several points indicate some plume conditions at 3 m depth, although results at 6 m depth (26-28 mg/L) are indicative of lake water conditions. Some potential for impingement at the

Burlington intake is suggested by point J (Figure 4.12), but the results are not as sensitive as the ammonia results.

4.5.3 Nitrogen Parameters

Ammonia was found to be a very sensitive indicator of plume conditions, even more so than conductivity. This is not surprising, since the average surface harbour concentration was over 50 times the average lake background surface value, and even higher in May and June due to the spring build-up of ammonia in the harbour. This results from winter and early spring ammonia loadings to the harbour when biological activity is minimal. Thus this parameter indicated failure to reach background conditions on May 20, as earlier discussed. The apparent sinking plume at the "background" location of June 28 is shown in Figure 4.13 as an elevation by a factor of almost 10 at 3 m, compared to the surface, and a smaller elevation at 11 m. (Compare with conductivity in Figure 4.8).

Ammonia data for June 30 (Figure 4.14) show considerable elevation at points A (surface) and E (surface and 6m), already referred to with chloride. Results are far more sensitive for ammonia, however. Elevated ammonia was also found at Point G, the northern extremity of the conductivity and chlorophyll plumes (Figures 4.3a-b).

On August 24 (Figure 4.15), severe elevation of ammonia concentrations was found throughout the conductivity plume (Figure 4.4a), including points I and J, which are on the edge of the conductivity plume. These latter points also showed higher concentrations of ammonia at 3 m depth than were observed at points closer to the canal. The sensitivity of ammonia as a plume tracer is also shown by the results at point B (surface), well beyond the conductivity plume. Even the background point (A) had a slight elevation at surface to 6 m. These data clearly indicate a potential for impingement of the harbour plume at the Burlington water treatment plant intake (point J, less than 1 km from the intake), and even at the Hamilton water treatment plant intake (very close to point B).

Most other survey dates show a similar tendency for elevated ammonia concentrations at distances from the canal greater than those shown by the conductivity plumes. More samples taken in areas closer to the water intakes would improve the definition of potential for impingement of harbour water; however, the possibility of other ammonia sources in the area such as creeks (as well as mineralization of organic N) must not be overlooked.

Total Kjeldahl nitrogen showed gradients similar to but less pronounced than those for ammonia, as the relative difference between harbour organic N and lake organic N is less than that for ammonia-N. Figure 4.16 shows a sample distribution.

Nitrite plus nitrate nitrogen also showed distributions similar to those of the other N parameters (see Figure 4.17 for an example). Concentrations are slightly increased on a relative basis in August due to nitrification, but results were generally consistent with those from earlier surveys.

4.5.4 Phosphorus

Assuming other sources such as runoff are small by comparison, the zone of influence of the harbour can be visualized as that area of western Lake Ontario where the total phosphorus value exceeds the Ontario guideline of 0.020 mg/L for the prevention of nuisance growths of algae. One would expect some correlation between the elevated phosphorus zone and the chlorophyll plumes. Results for June 29 and 30 (Figure 4.18 and 4.19) show that this is generally true. For example, point A1 (June 29) and A (June 30) had surface total P values of 0.021 mg/L and were included in the chlorophyll plume. but not in the conductivity plume. In August (data not shown), total phosphorus values tended to be lower, with the elevated zone being smaller than the August 24 chlorophyll plume but similar to the August 26 plume. Total phosphorus increased slightly again in October.

Filtered reactive phosphorus concentrations were generally small and variable, except for higher values in areas very close to the canal piers.

4.5.5 Turbidity and Suspended Solids

Figure 4.20 shows the turbidity distribution on August 24. No strong gradient away from the canal was found, and high values occurred as frequently at depth as at the surface. The same is true for turbidity on most other dates, and for suspended solids. These parameters, therefore, are not a good indicator of plume conditions. They are undoubtedly affected by numerous other sources such as rainfall-induced runoff, shoreline erosion and bottom sediment resuspension. A plume of turbid water was visible on August 26 (Figure 4.21) following a rainfall of 15 mm on August 24 and 32 mm on August 25. Turbidity at the two water treatment plant intakes was highest on July 29 (8.3 and 8.6 FTU at Hamilton and Burlington, respectively), following a 16 mm rainfall on July 28. Due to their diverse sources, these parameters are of little interest in this study.

4.5.6 Heavy Metals

Iron, manganese and zinc were chosen for measurement as they all have large, known industrial loadings to the harbour (MOE 1985). Copper was also chosen as it frequently exceeds the Provincial Water Quality Objective of 5 ug/L in nearshore Lake Ontario; for example in 1981, average Toronto Harbour values were 4 ug/L with 23% above Objective; and 15% above Objective in the Toronto nearshore region of the lake.

Although the highest iron concentrations were primarily found in the plume areas near the canal, high iron concentrations were occasionally found at more distant points or in depth samples. Thus other iron sources appeared to exist. Indeed, iron correlated strongly with turbidity in the nearshore region on August 26 after the runoff mentioned above. The observed iron concentrations, however, were not of great concern as they exceeded the Provincial Water Quality Objective of 0.3 mg/L only three times (about 1% of the lake samples). These occurred on May 21, at 6 m depth about 0.3 km north of the canal (0.43 mg/L), on May 24 at the surface, 1.5 km north of the canal and 0.2 km from shore (0.472 mg/L), and on August 28 at the surface within 100m of the canal piers (0.40 mg/L).

The other three metals also showed no consistent spatial variations with many results being close to the detection limit. Copper was above the Objective of 5 ug/L in 28% of the background samples, with an overall range of 2 to 9 ug/L; in all the lake samples taken, it exceeded Objectives 26% of the time. Zinc did not exceed the Objective of 30 ug/L in the background samples; it exceeded the Objective in only 2.5% of all lake samples.

4.6 References

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Poulton, D.J. 1986. Hamilton Harbour Trace Contaminants, 1982-1983. Loadings to, and Concentrations in, the Harbour. Water Resources Branch, Ontario Ministry of the Environment.

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TABLE 4.1

Burlington Pier Meteorological Data (hourly)
Measured on Plume Tracking Dates

Plume Tracking Date (1982)	Average Wind Direction (Degrees)	Speed (km/h)	Air Temperature °C Maximum	Minimum	Precipitation* (mm)
May 20	NNE (21)	15.8	19.5	9.4	5.6
May 21*	ENE	24.5	16.9	8.5	-
May 24*	ENE	8.3	18.1	6.5	-
June 28*	ENE	6.2	24.4	15.6	3.2
June 29*	Variable	9.4	25.8	16.5	3.2
June 30*	NW	16.7	22.7	11.7	-
Aug. 24	WSW (261)	8.1	23.7	15.3	14.8
Aug. 26	SW (233)	12.2	24.2	15.6	-
Aug. 27	W (266)	11.9	23.1	16.9	0.3
Aug. 28	WNW (286)	15.8	16.2	8.7	Trace
Oct. 19	SWS (203)	13.0	19.6	11.3	-
Oct. 22	NW (309)	4.3	6.5	2.1	-
Oct. 23	WNW (293)	6.8	10.3	5.0	-

* data obtained from Environment Canada (Hamilton Airport); Burlington Pier - data not available or not monitored.

TABLE 4.2

CHLOROPHYLL - FLUORESCENCE CALIBRATION CURVES
LAKE ONTARIO

Date	# Obs.	Variable	Regression Coefficient	Significance of F	Significance of t	R^2	Standard Error
82/05/20	24	Intercept	-16.105			0.951	4.925
		Fluorescence	16.625	0.0000	0.0000		
		Temperature	1.1679		0.4496		
82/05/21	17	Intercept	-14.867			0.945	4.150
		Fluorescence	18.554	0.0000	0.0000		
		Temperature	0.910		0.0552		
82/05/24	26	Intercept	-16.126			0.559	8.504
		Fluorescence	26.586	0.00001	0.00001		
82/06/28	19	Intercept	-8.242			0.708	1.154
		Fluorescence	15.310	0.0001	0.0058		
		Time	0.0104		0.0002		
82/06/29	20	Intercept	-22.075			0.828	2.333
		Fluorescence	39.835	0.00001	0.0002		
		Temperature	1.539		0.0005		
		Time	-0.0121		0.0244		
82/06/30	20	Intercept	-13.628			0.766	2.089
		Fluorescence	62.144	0.0000	0.0005		
		Temperature	0.5609		0.0179		
82/08/24	33	Intercept	-13.233		0.0001	0.892	2.534
		Fluorescence	174.397	0.0001	0.0001		
		Temperature	0.9191	0.0001	0.0001		
82/08/26	39	Intercept	-20.013		0.0001	0.895	2.270
		Fluorescence	136.472	0.0001	0.0002		
		Temperature	1.616	0.0001	0.0001		
82/08/27	37	Intercept	-22.377		0.0001	0.924	2.620
		Fluorescence	129.216	0.0001	0.0001		
		Temperature	1.923	0.0001	0.0001		
82/08/28	16	Intercept	-15.743		0.0001	0.939	2.336
		Fluorescence	181.291	0.0001	0.0030		
		Temperature	1.211	0.0032	0.0032		
82/10/19	20	Intercept	-2.793		0.0001	0.962	1.119
		Fluorescence	351.699	0.0001	0.0001		
82/10/22	20	Intercept	-4.8280		0.0001	0.963	1.487
		Fluorescence	417.5545	0 0001	0.0001		
82/10/23	33	Intercept	-5.470		0.0001	0.912	1.851
		Fluorescence	372.913	0.0001	0.0001		

TABLE 4.3

Conductivity and Chlorophyll Values
At Station 258 and Lake Background

Date	Conductivity (umho/cm)		Chlorophyll (ug/L)	
	258	background	258	background
May 20	625	365	55.3	6.5
May 21	637	345	54.6	2.8
May 24	639	346	35.3	11.4
June 28	542	285	4.7	3.4
June 29	495	290	17.9	3 6
June 30	605	329	13.0	3.0
Aug. 24	534	345	24.3	4.1
Aug. 26	493	337	23.5	2.0
Aug. 28	494	335	25.6	3.1
Oct. 19	523	342	12.8	6.9
Oct. 22	518	346	21.5	2.8
Oct. 23	515	335	15.4	1.6

TABLE 4.4

Average Water Chemistry Results for
Hamilton Harbour Station 258, 1982

Parameter	0.2m		3m		6m		10m		20m	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
NH_3-N	1.661	0.892	0.984	0.674	1.729	0.907	1.131	0.583	1.816	0.993
TKN	2.559	1.177	1.96	0.796	2.537	1.067	1.701	0.748	2.468	1.220
(NO_2+NO_3)-N	2.042	0.390	2.038	0.295	2.054	0.288	1.713	0.348	1.458	0.338
Total P	0.070	0.025	0.055	0.008	0.065	0.025	0.045	0.018	0.058	0.024
FRP	0.023	0.012	0.023	0.013	0.028	0.027	0.018	0.010	0.030	0.019
Cl	68.3	15.7	61.9	10.9	66.6	15.5	55.0	11.3	59.5	17.3
Turbidity	3.00	1.07	3.35	0.92	3.47	1.11	3.60	1.20	3.96	0.51
Susp. Solids	3.41	1.36	3.84	1.11	3.71	1.59	4.52	1.47	3.73	1.65
Cu	0.006	0.002	0.007	0.002	0.006	0.002	0.005	0.001	0.006	0.003
Fe	0.122	0.068	0.202	0.157	0.148	0.087	0.205	0.090	0.209	0.134
Mn	0.038	0.027	0.047	0.032	0.040	0.026	0.083	0.067	0.239	0.199
Zn	0.023	0.009	0.042	0.060	0.024	0.012	0.019	0.008	0.020	0.011
No. of obs.	13		8		13		8		12	

Note: All concentrations are in mg/L except turbidity (FTU)

TABLE 4.5

Average Water Chemistry Results for
Lake Ontario Background Location, 1982

Parameter	0.2m		3m		6m		10m		20m	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
NH_3-N	0.031	0.025	0.025	0.020	0.023	0.021	0.037	0.035	0.021	0.012
TKN	0.312	0.087	0.271	0.056	0.293	0.058	0.223	0.054	0.229	0.046
(NO_2+NO_3)-N	0.306	0.079	0.319	0.094	0.312	0.079	0.311	0.077	0.345	0.045
Total P	0.013	0.002	0.014	0.002	0.015	0.003	0.011	0.003	0.011	0.003
FRP	0.004	0.002	0.005	0.003	0.004	0.001	0.004	0.002	0.004	0.002
Cl	26.1	1.5	26.1	1.3	27.0	1.7	26.8	1.4	26.4	0.5
Turbidity	1.52	0.69	1.68	0.59	1.60	0.60	1.67	0.69	1.70	0.57
Susp. Solids	1.11	0.70	1.51	0.78	1.61	1.11	1.39	0.82	1.54	0.66
Cu	0.005	0.002	0.004	0.002	0.004	0.002	0.004	0.002	0.005	0.003
Fe	0.031	0.015	0.035	0.024	0.037	0.031	0.041	0.017	0.043	0.015
Mn	0.003	0.001	0.003	0.009	0.003	0.001	0.003	0.001	0.003	.001
Zn	0.006	0.003	0.005	0.003	0.004	0.003	0.005	0.003	0.004	0.003
No. of obs.	10		7		11		8		11	

Note: All concentrations are in mg/L except turbidity (FTU)

TABLE 4.6

Spring Nearshore Lake Ontario Averages
Non-Impacted Areas (MOE 1980)

Parameter	1976		1977		1978		1979	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
NH_3-N	.016	.008	.011	.004	.015	.008	.025	.033
NO_2+NO_3-N	.293	.016	.297	.017	.322	.016	.349	.02
Total P	.020	.003	.019	.007	.016	.003	.017	.002
FRP	.004	.001	.007	.001	.007	.002	-	-
Si	.272	.050	.104	.031	.166	.037	.238	.065
Conductivity (umho/cm)	330	6	347	18	326	4	349	10
Secchi depth(m)	3.7	.67	6.9	.58	6.0	.49	6.9	.80
Chlorophyll a (ug/L)	2.6	.65	-	-	2.1	.47	3.6	.81

Note: All concentrations are in mg/L except where otherwise noted.

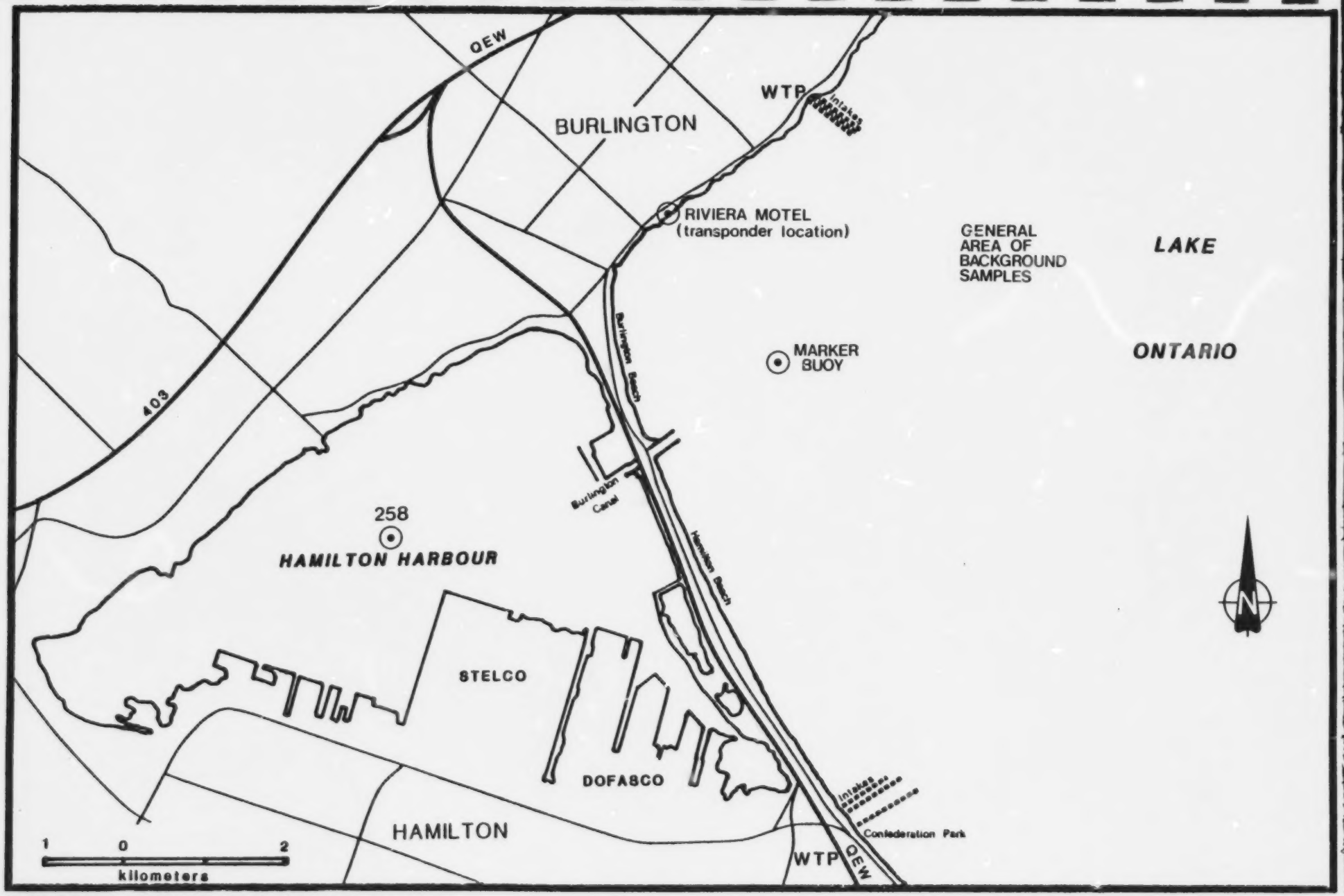

FIGURE 4.1: PLUME TRACKING STUDY AREA

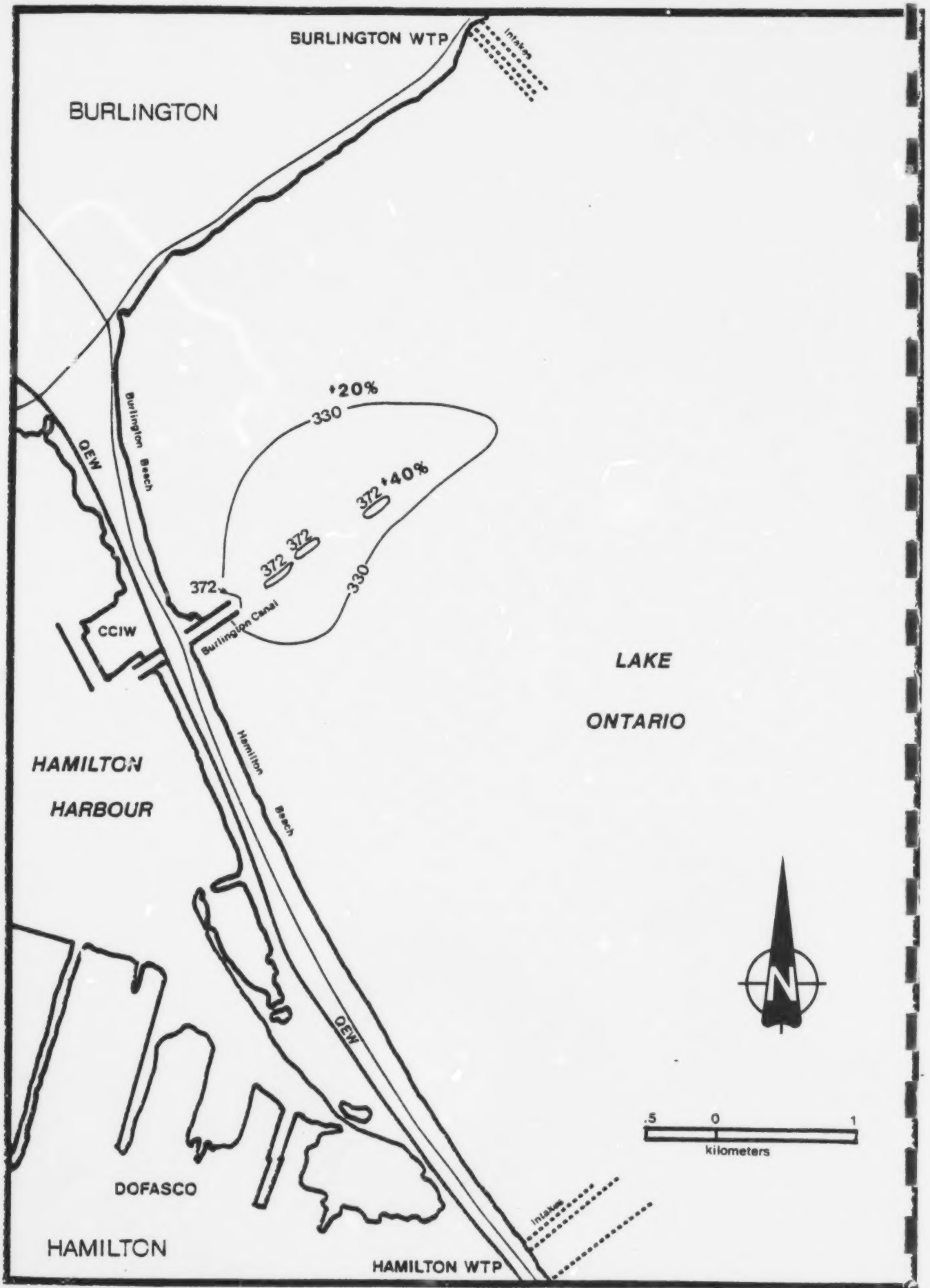

FIG.4.2a : CONTOURS OF CONDUCTIVITY IN WESTERN LAKE ONTARIO JUNE 29, 1982, 1128-1623 h.

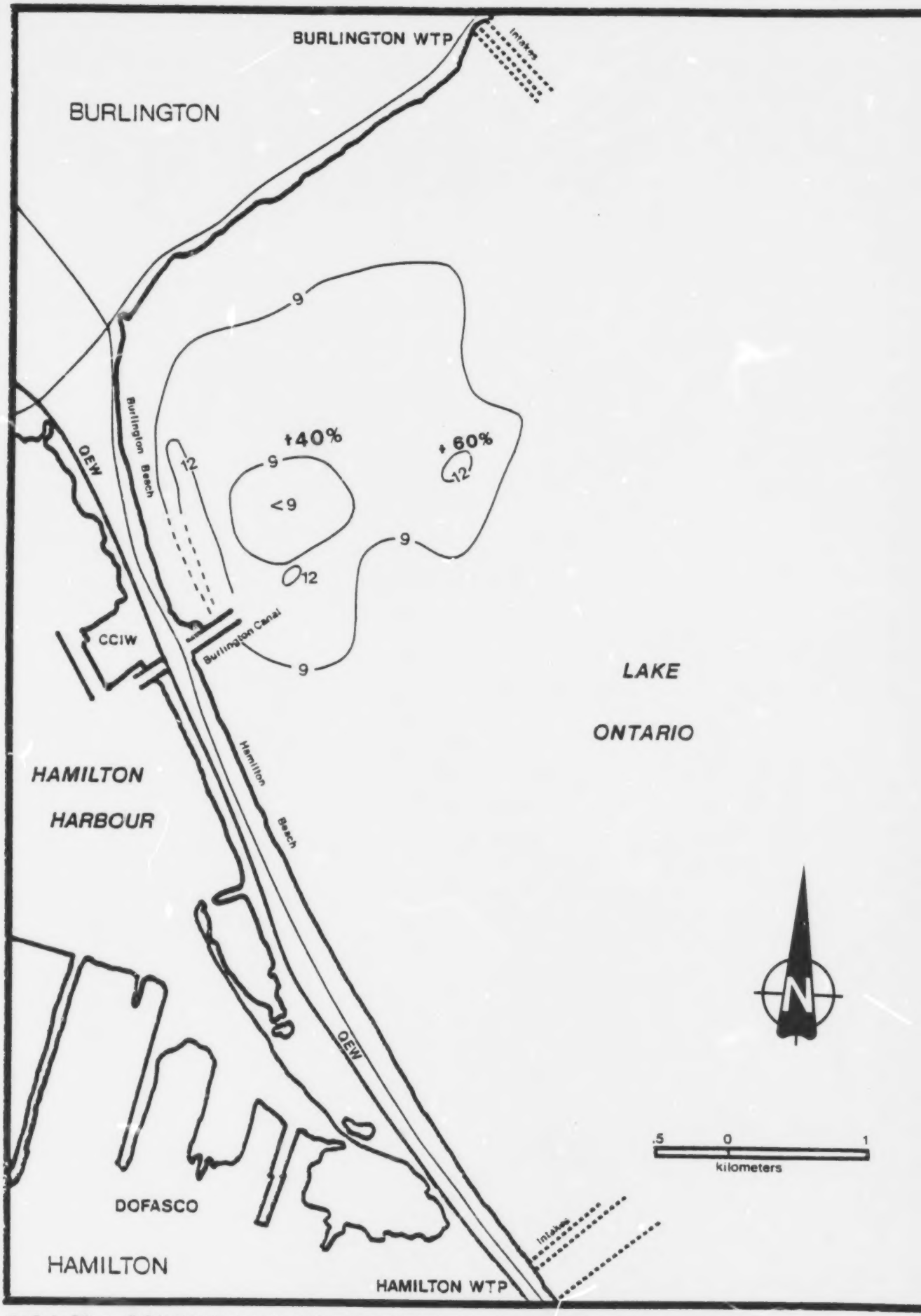

FIG4.2b : CONTOURS OF CHLOROPHYLL IN WESTERN LAKE ONTARIO JUNE 29, 1982, 1128-1623 h.

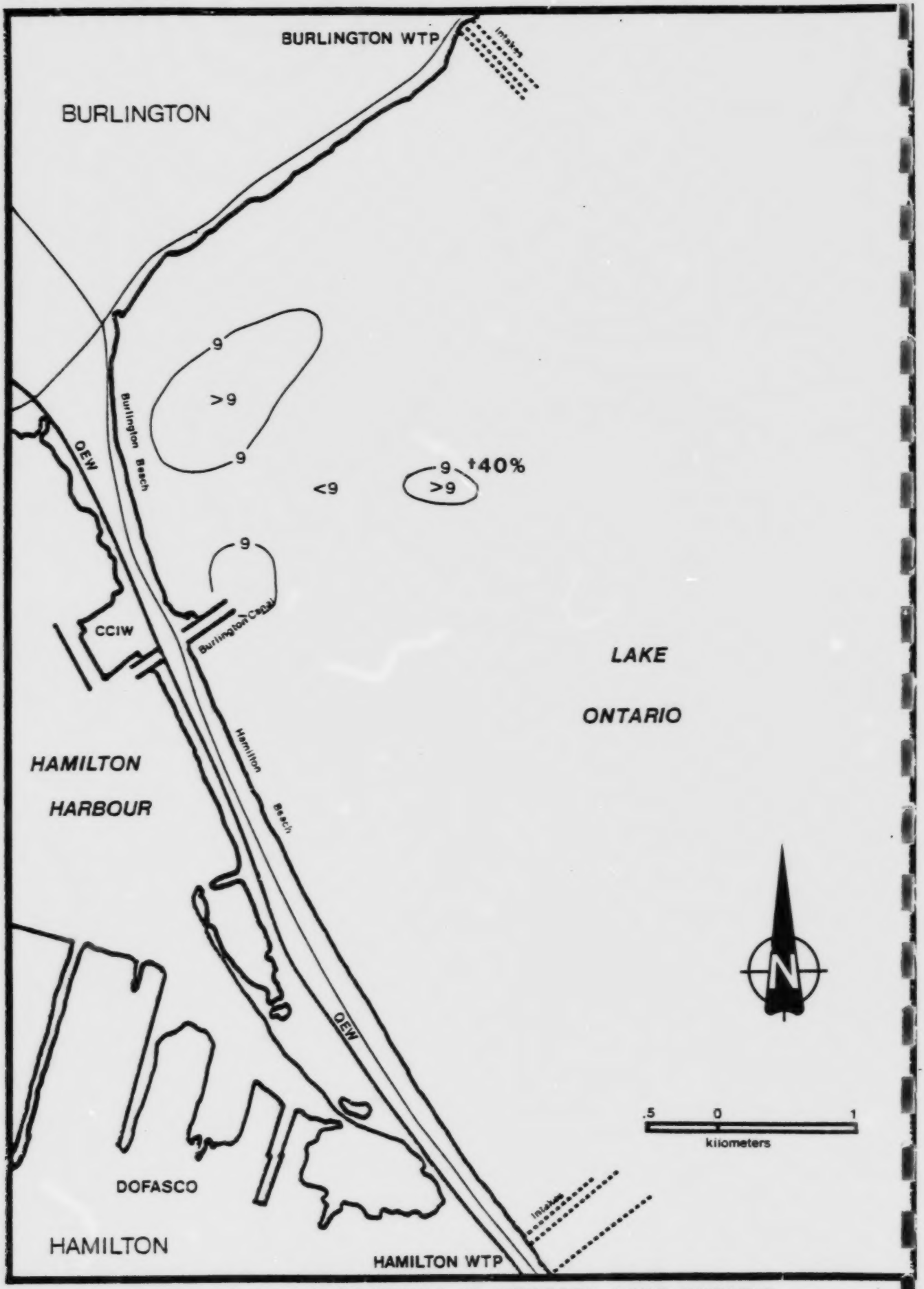

FIG4.2c : CONTOURS OF CHLOROPHYLL IN WESTERN LAKE ONTARIO JUNE 29,1982, 1623-1826 h

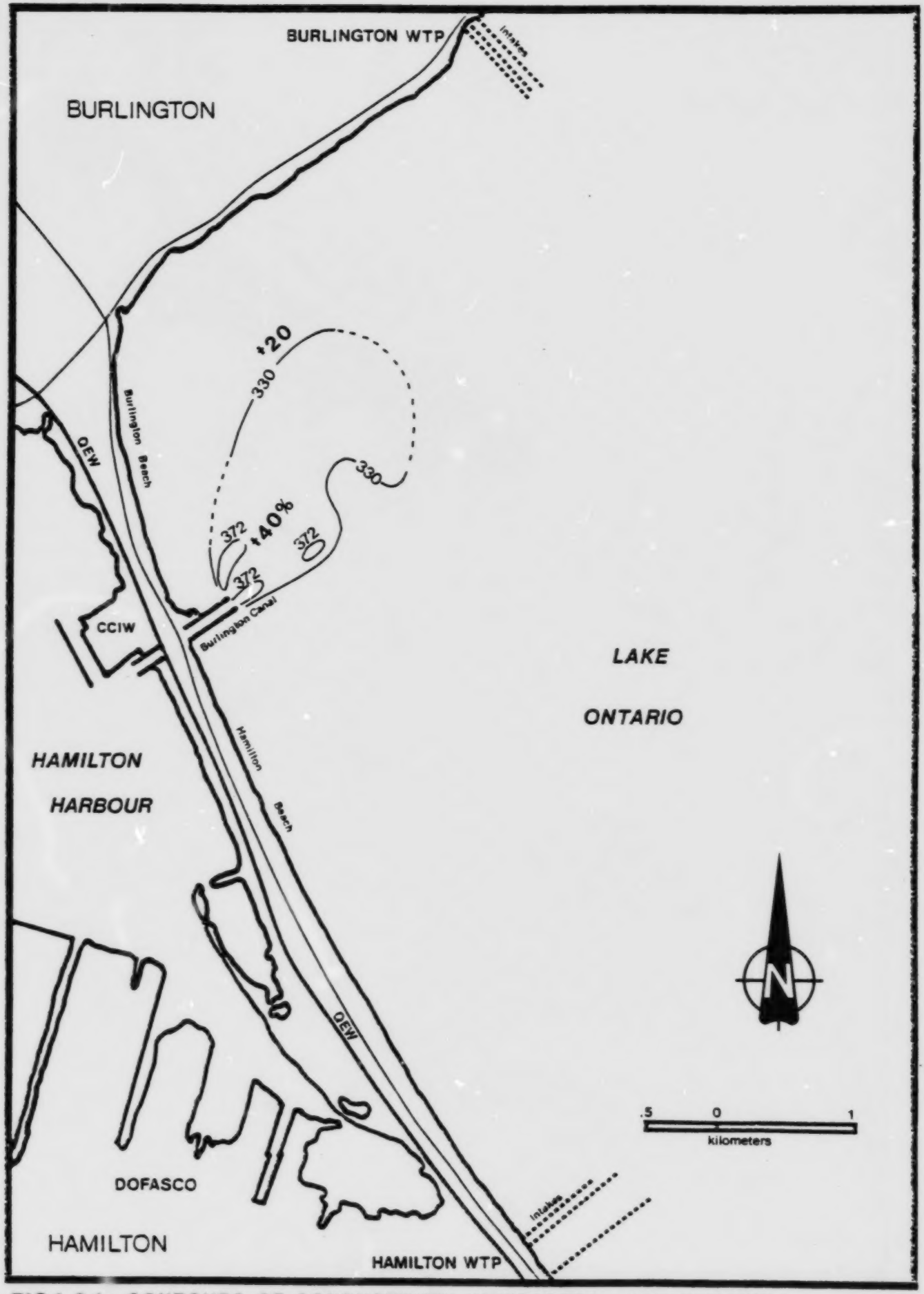

FIG4.2d : CONTOURS OF CONDUCTIVITY IN WESTERN LAKE ONTARIO JUNE 29, 1982, 1623-1826 h.

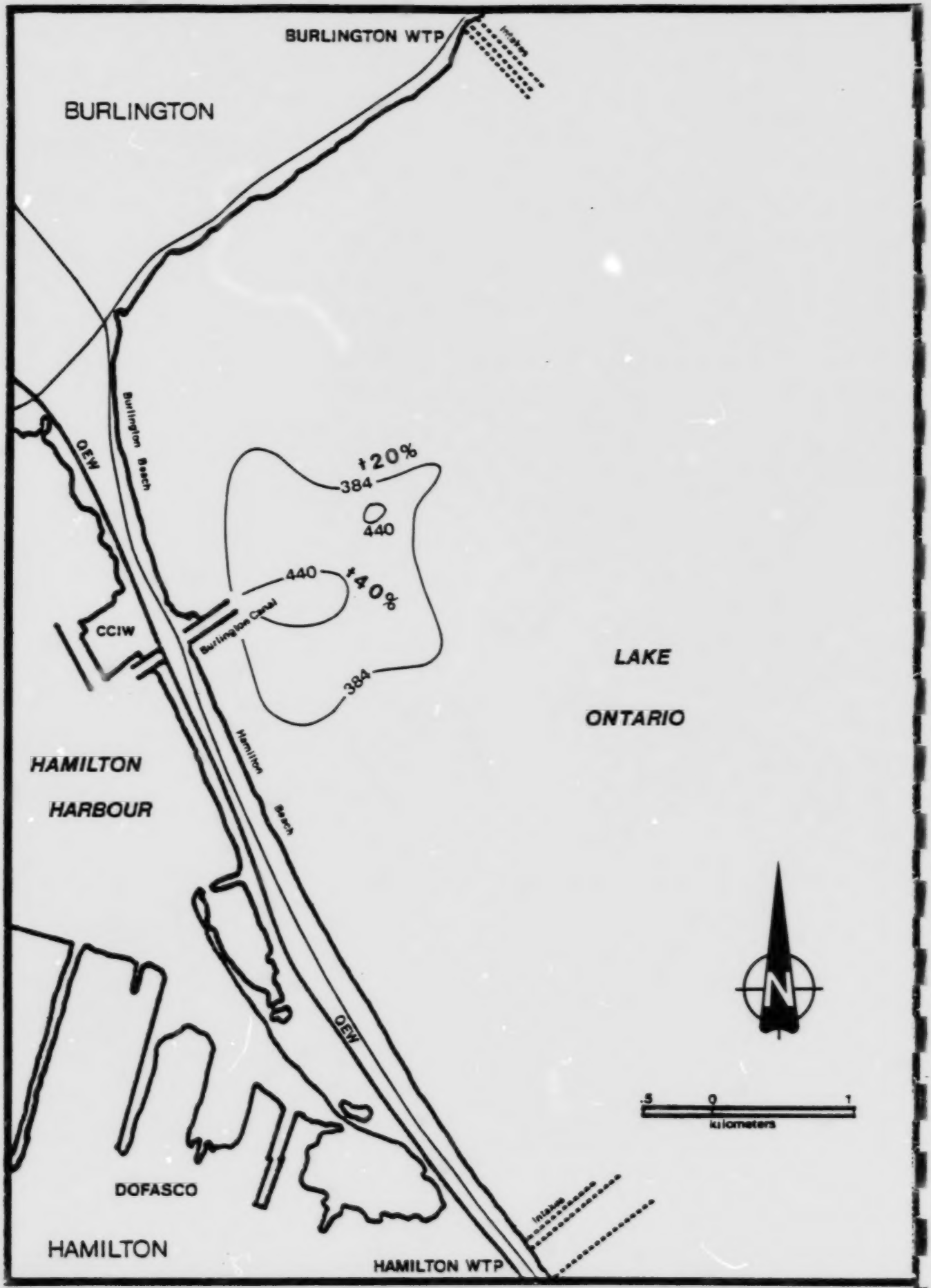

FIG4.3a : CONTOURS OF CONDUCTIVITY IN WESTERN LAKE ONTARIO JUNE 30, 1982

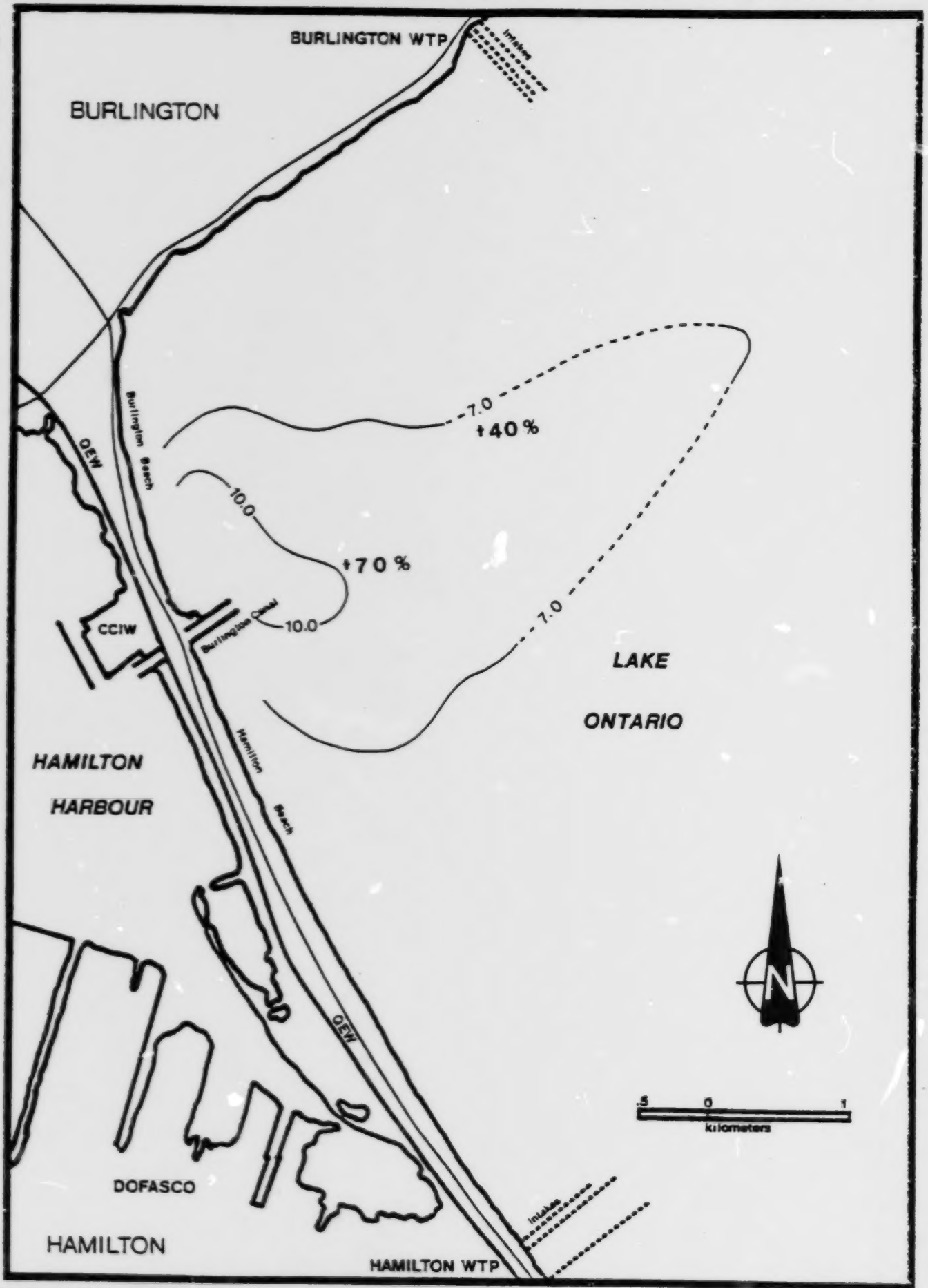

FIG 4.3b: CONTOURS OF CHLOROPHYLL IN WESTERN LAKE ONTARIO JUNE 30, 1982

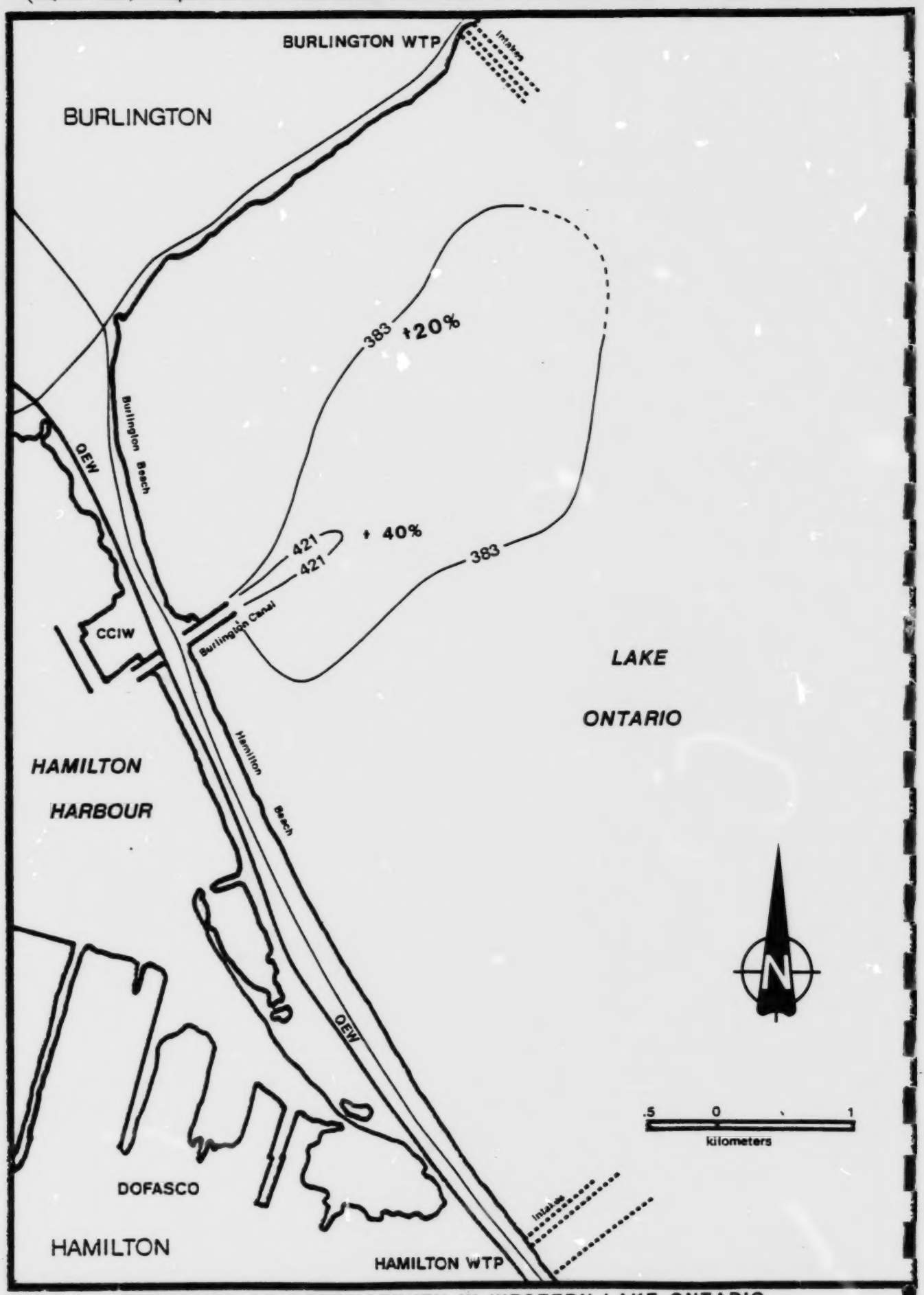

FIG4.4a: CONTOURS OF CONDUCTIVITY IN WESTERN LAKE ONTARIO AUGUST 24, 1982

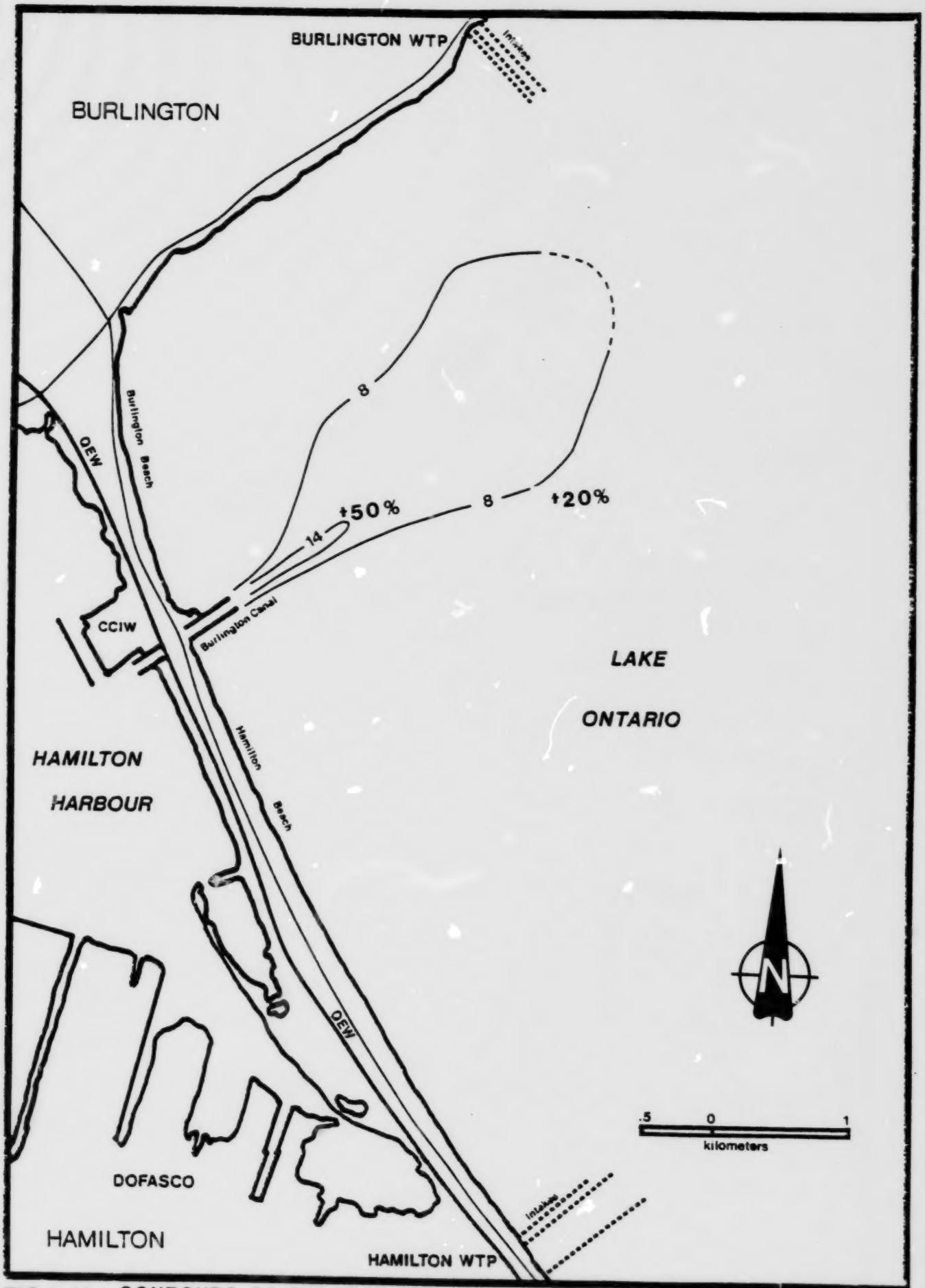

FIG4.4b: CONTOURS OF CHLOROPHYLL IN WESTERN LAKE ONTARIO AUGUST 24, 1982

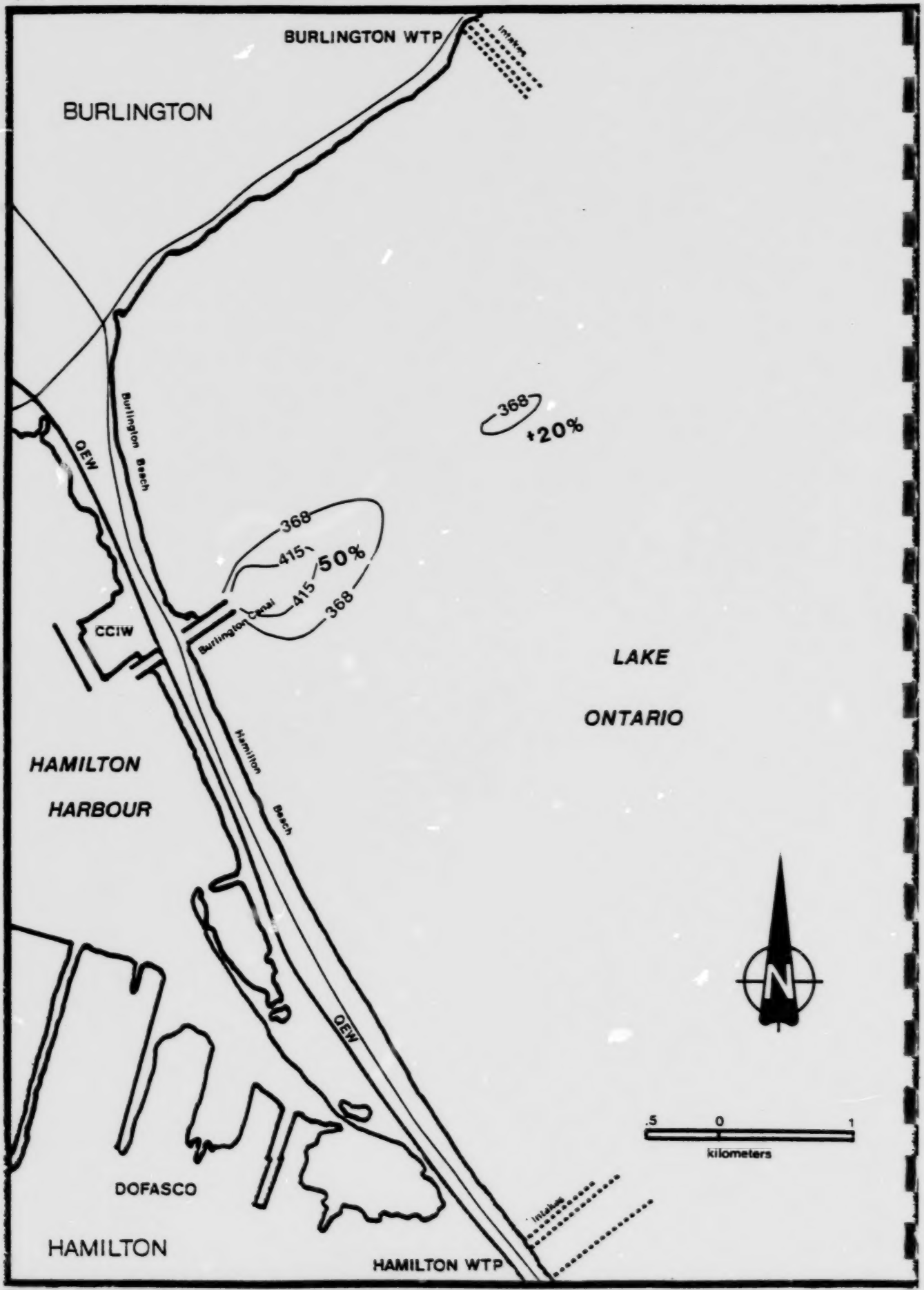

FIG 4.5a: CONTOURS OF CONDUCTIVITY IN WESTERN LAKE ONTARIO
AUGUST 26, 1982

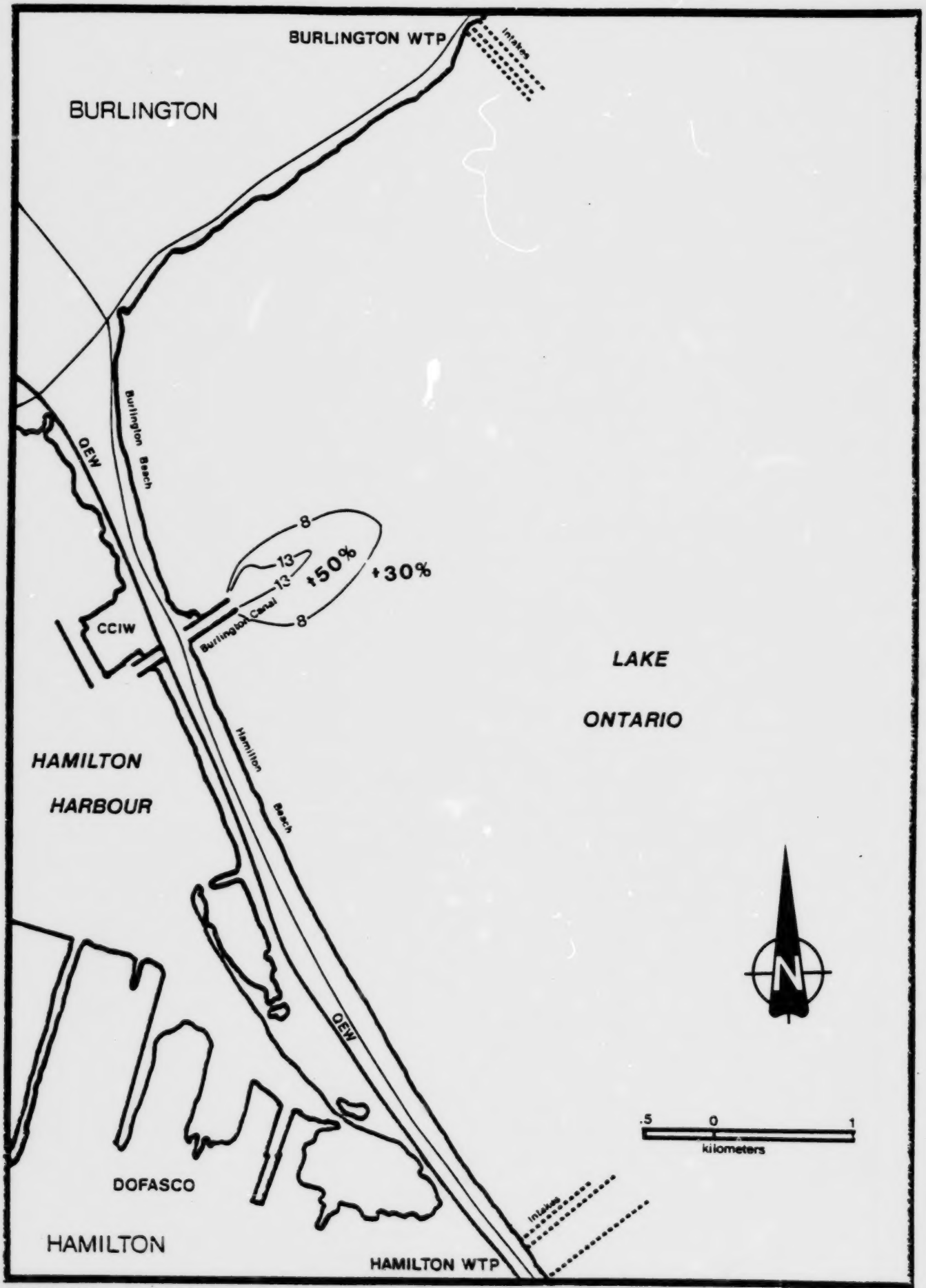

FIG4.5b: CONTOURS OF CHLOROPHYLL IN WESTERN LAKE ONTARIO AUGUST 26,1982

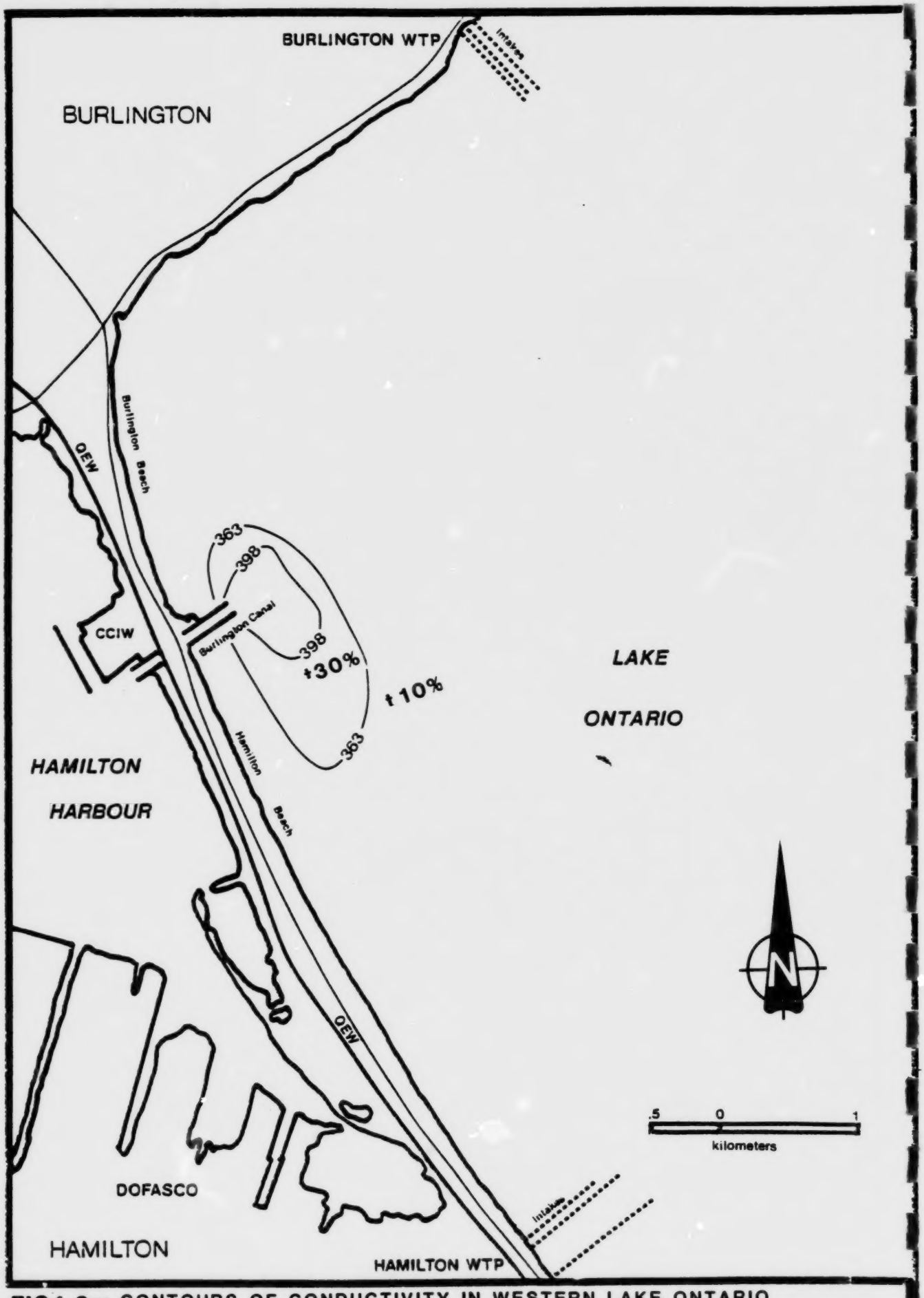

FIG4.6a: CONTOURS OF CONDUCTIVITY IN WESTERN LAKE ONTARIO OCTOBER 22, 1982

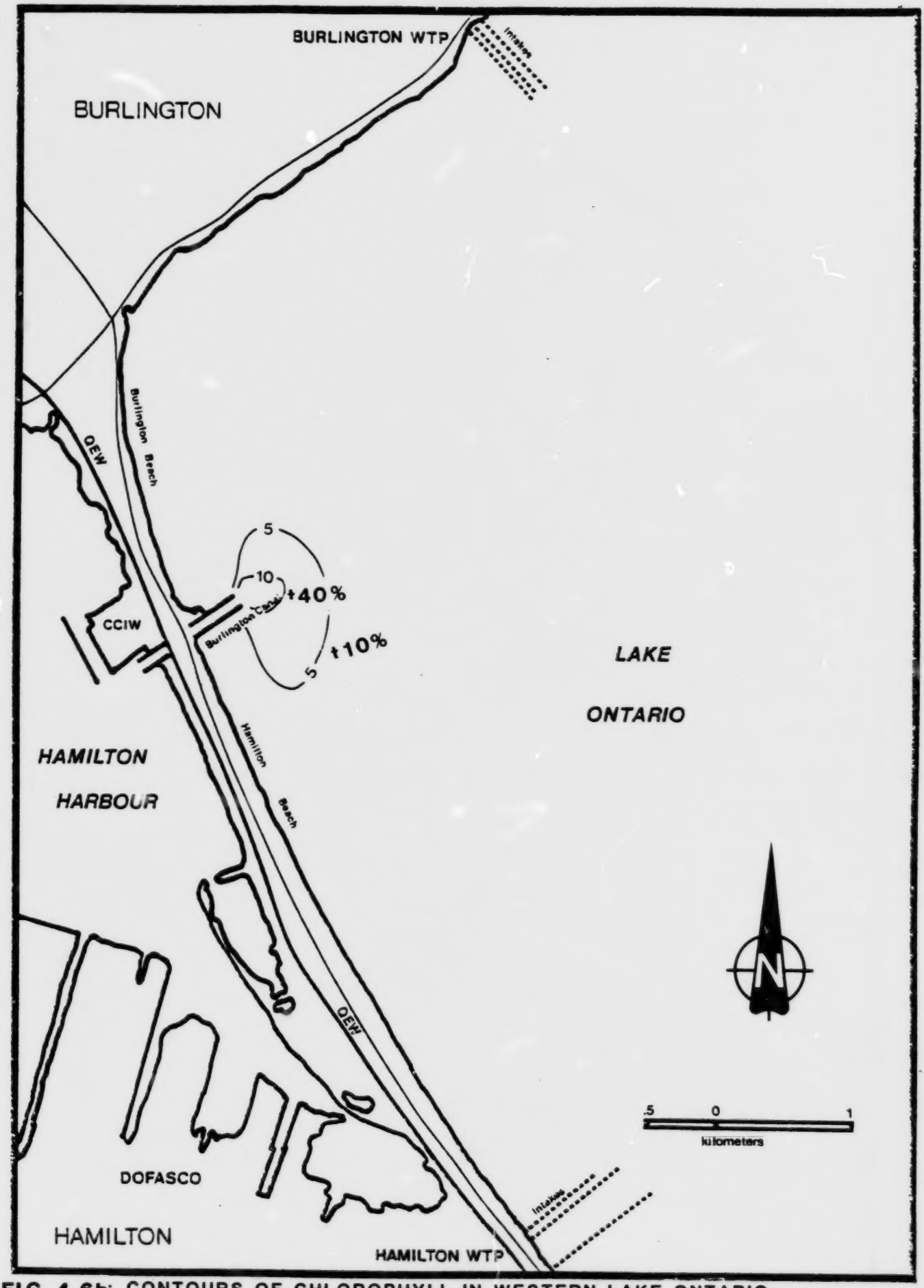

FIG 4.6b: CONTOURS OF CHLOROPHYLL IN WESTERN LAKE ONTARIO OCTOBER 22, 1982

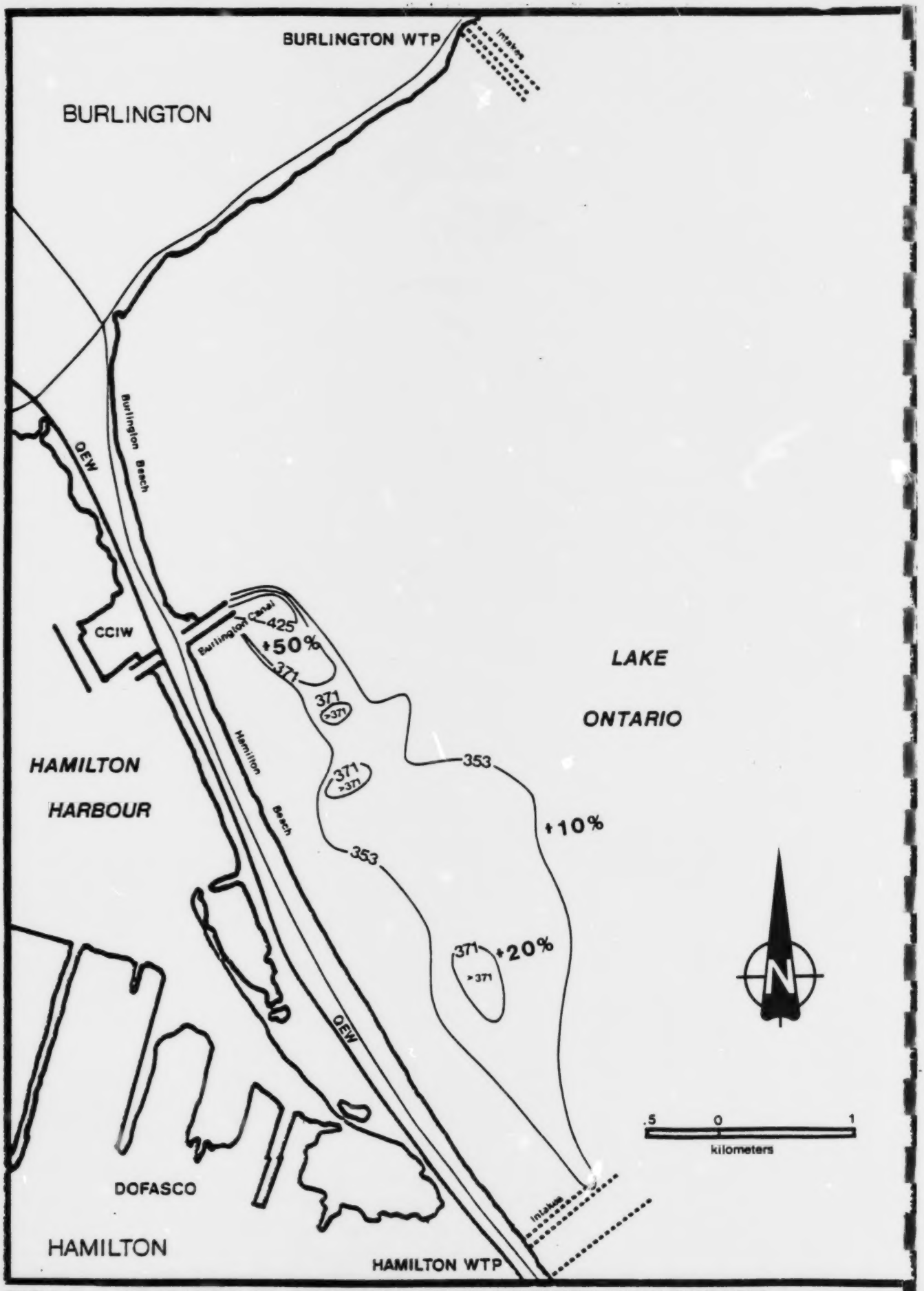

FIG4.7a: CONTOURS OF CONDUCTIVITY IN WESTERN LAKE ONTARIO OCTOBER 23, 1982

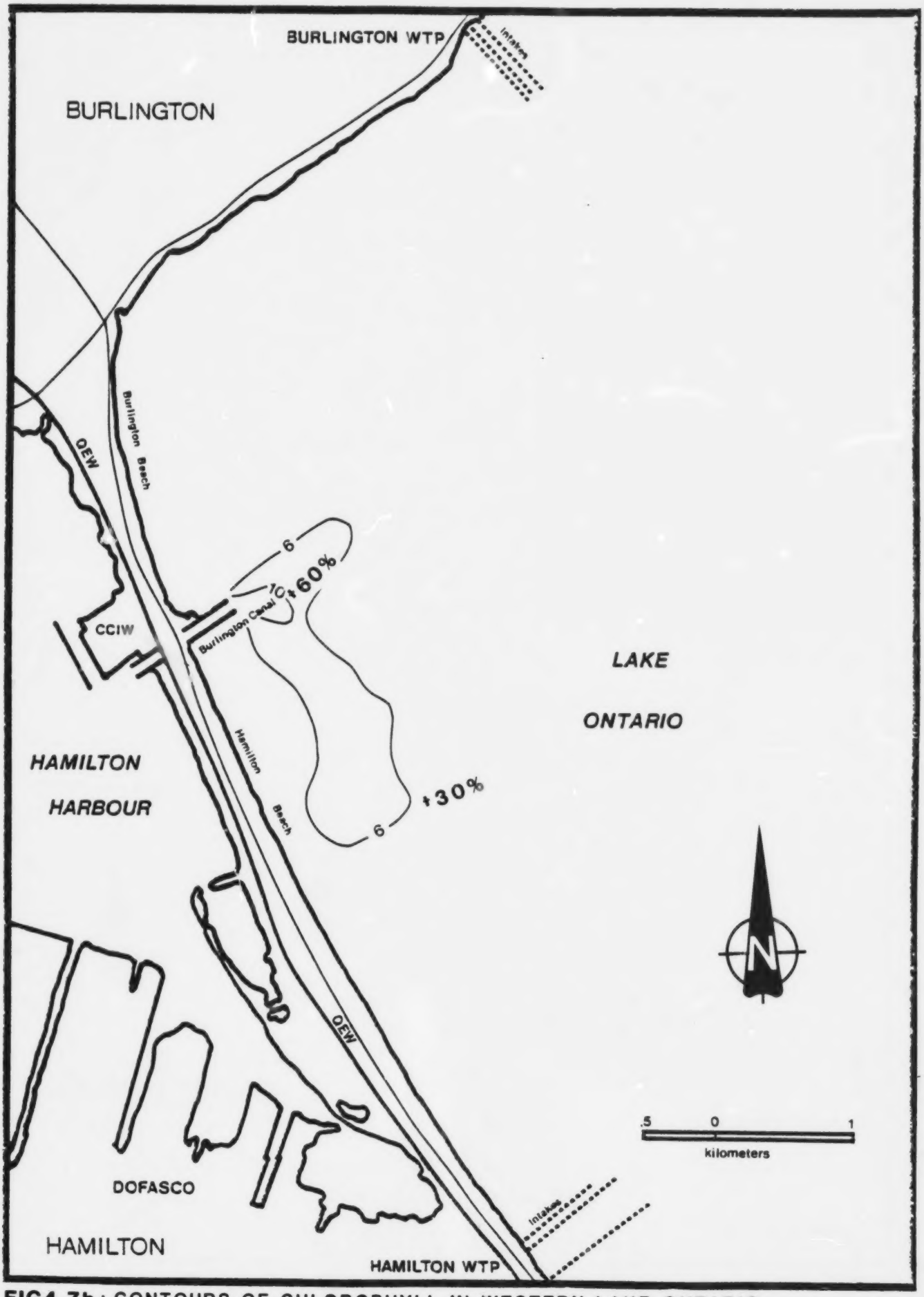

FIG4.7b: CONTOURS OF CHLOROPHYLL IN WESTERN LAKE ONTARIO OCTOBER 23, 1982

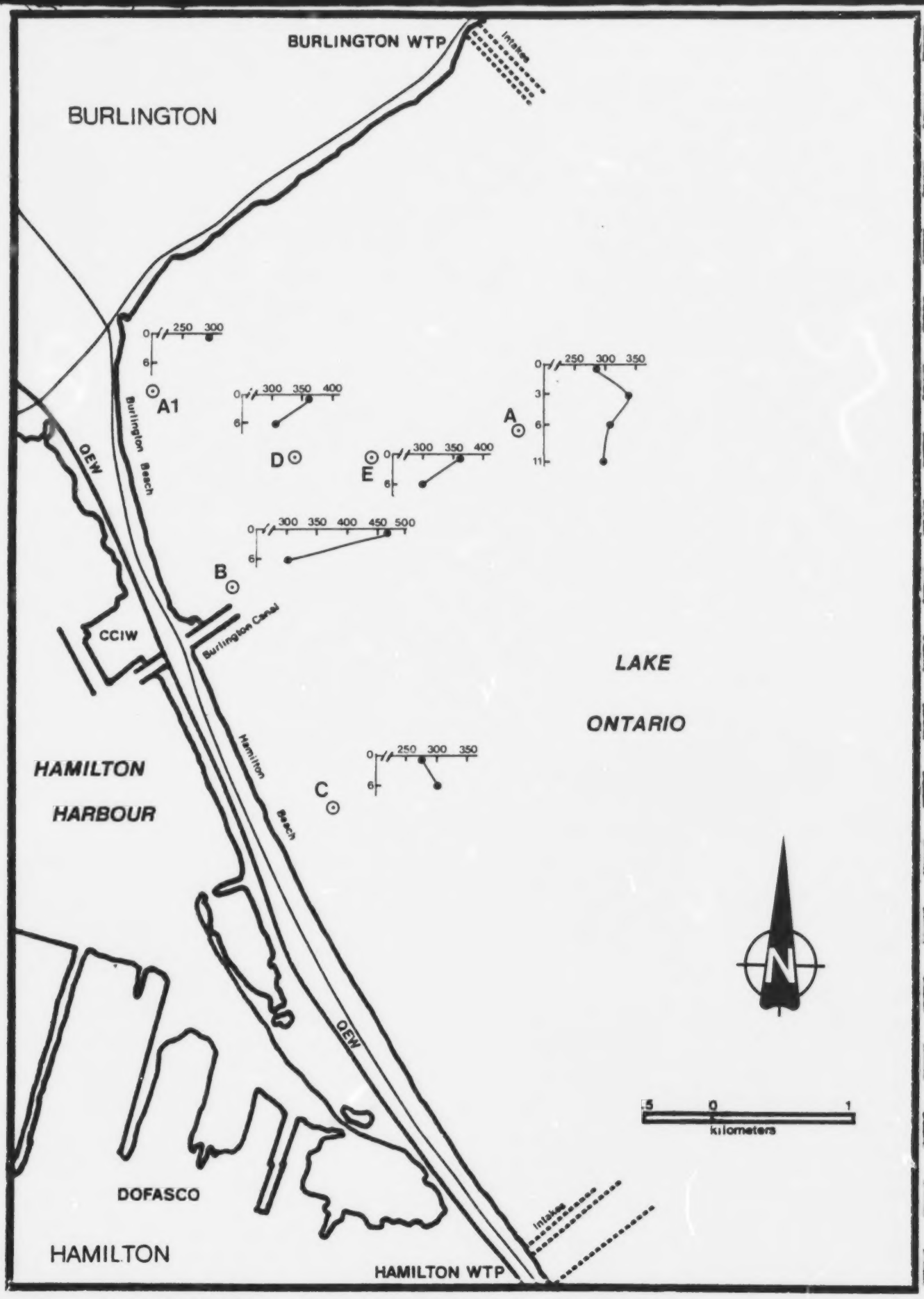

FIG 4.8: CONDUCTIVITY (umho/cm) WITH DEPTH (m) JUNE 28, 1982

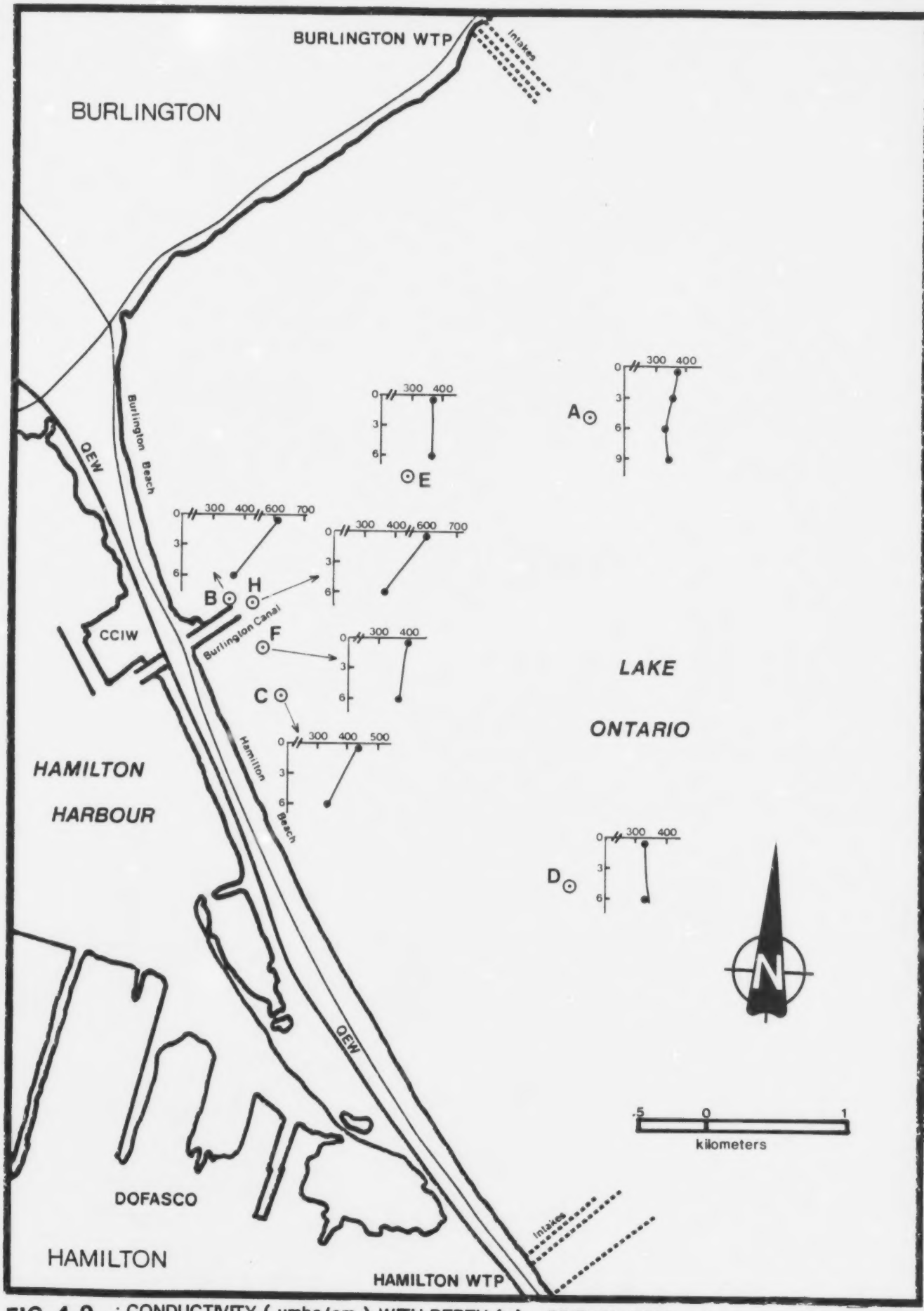

FIG 4.9 : CONDUCTIVITY (umho/cm) WITH DEPTH (m) JUNE 30, 1982

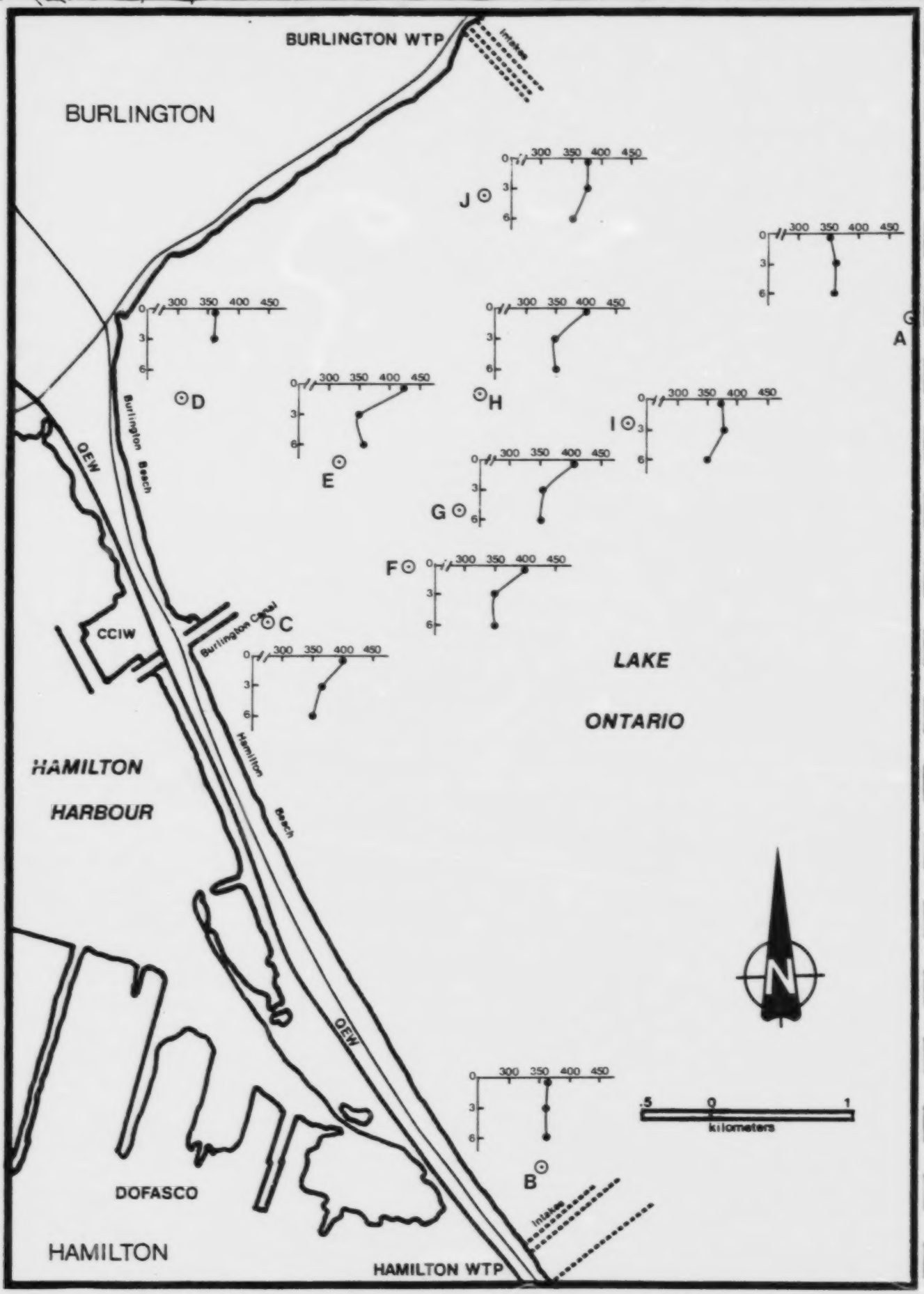

FIG4.10: CONDUCTIVITY (umho/cm) WITH DEPTH (m) AUGUST 24, 1982

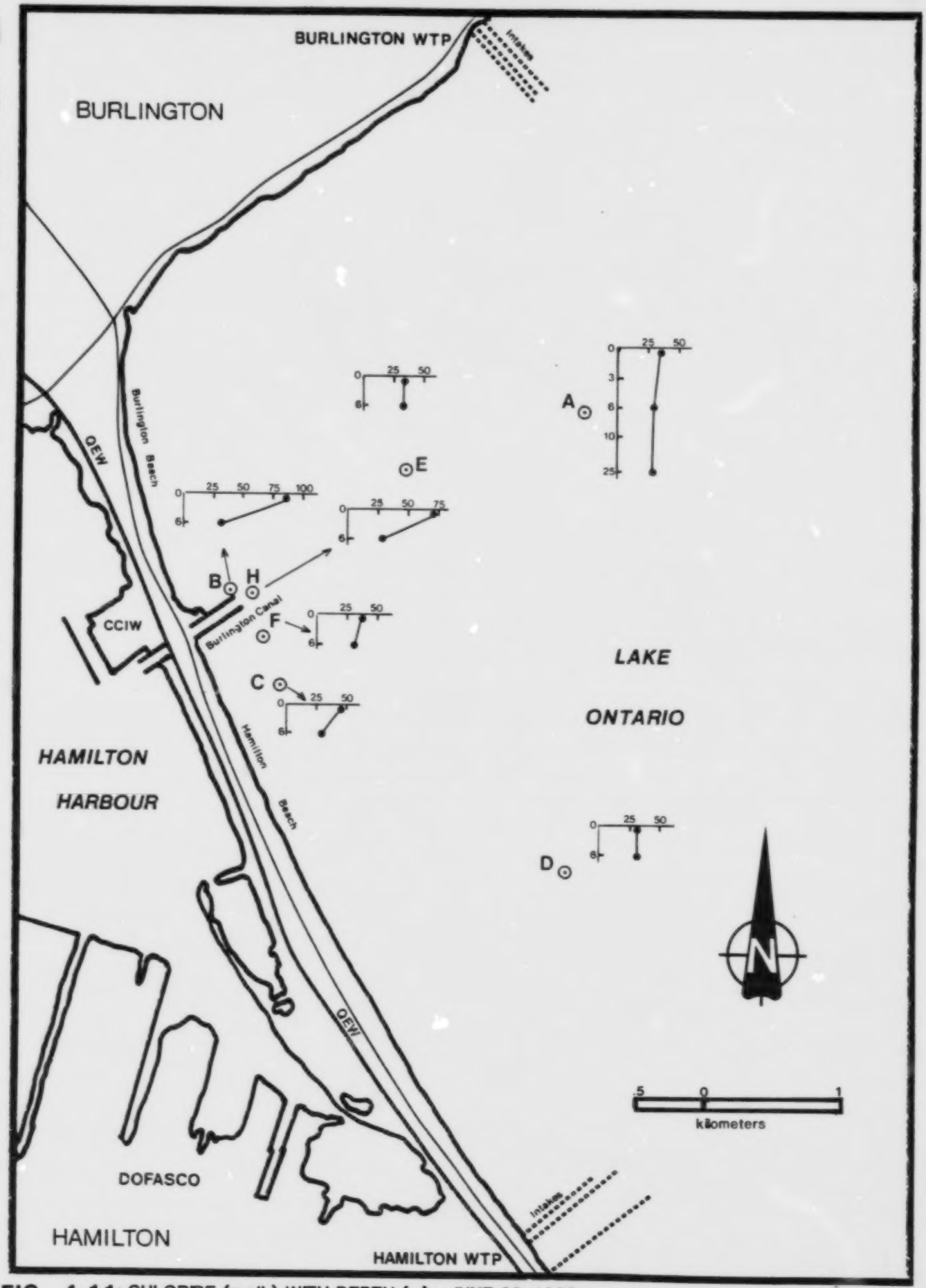

FIG 4.11: CHLORIDE (mg/L) WITH DEPTH (m) JUNE 30, 1982

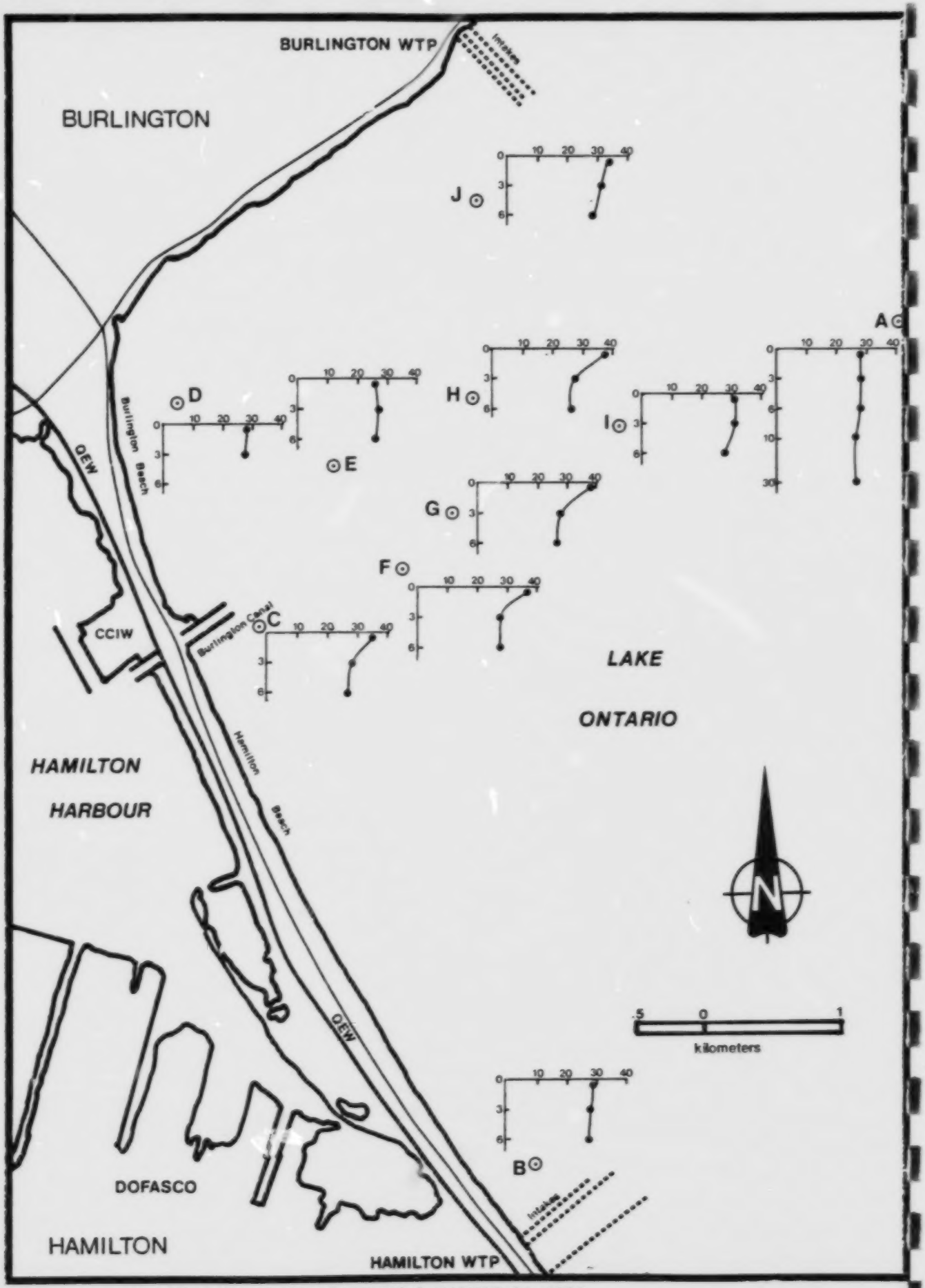

FIG 4.12: CHLORIDE (mg/L) WITH DEPTH (m) AUGUST 24, 1982

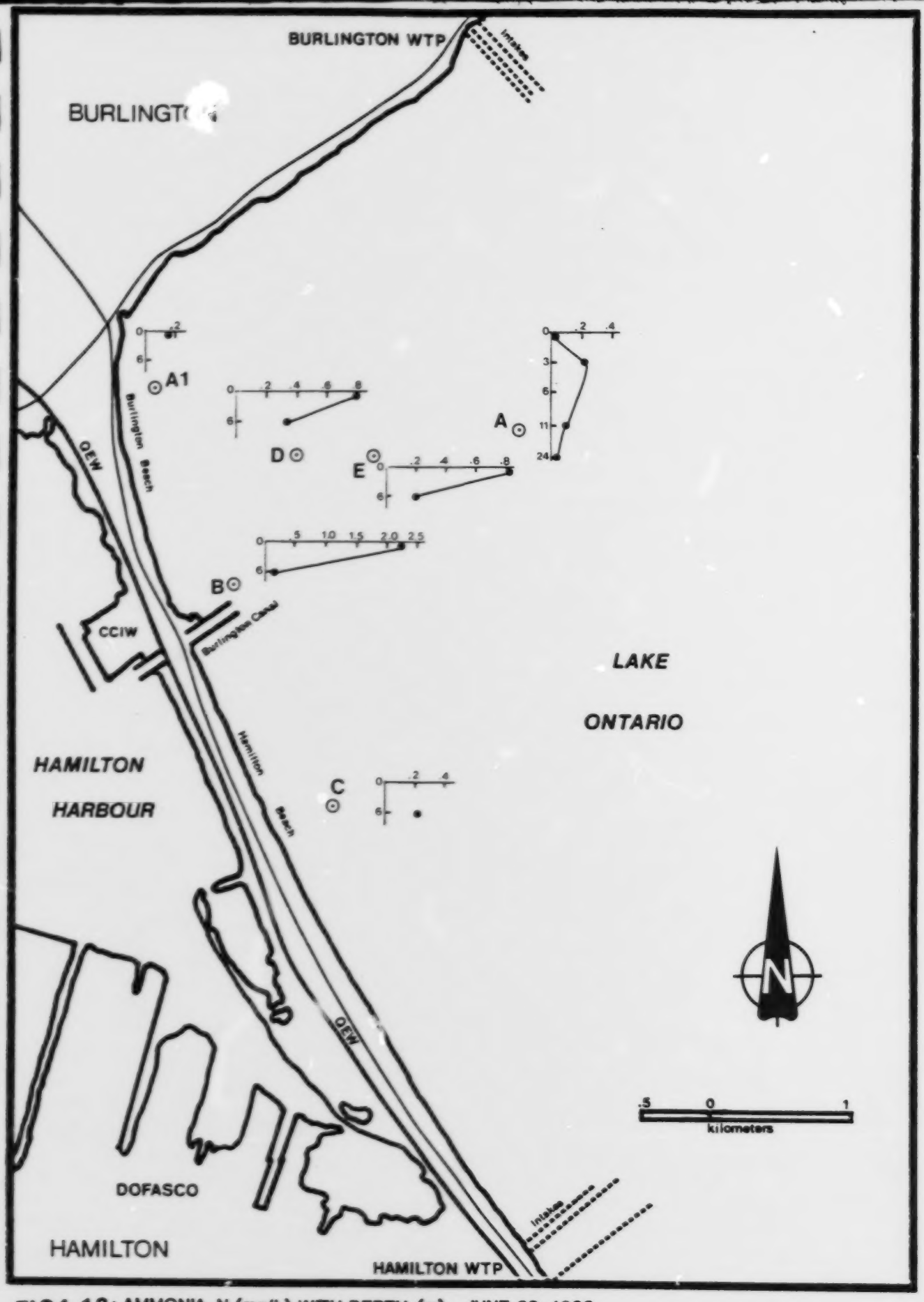

FIG4.13: AMMONIA-N (mg/L) WITH DEPTH (m) JUNE 28, 1982

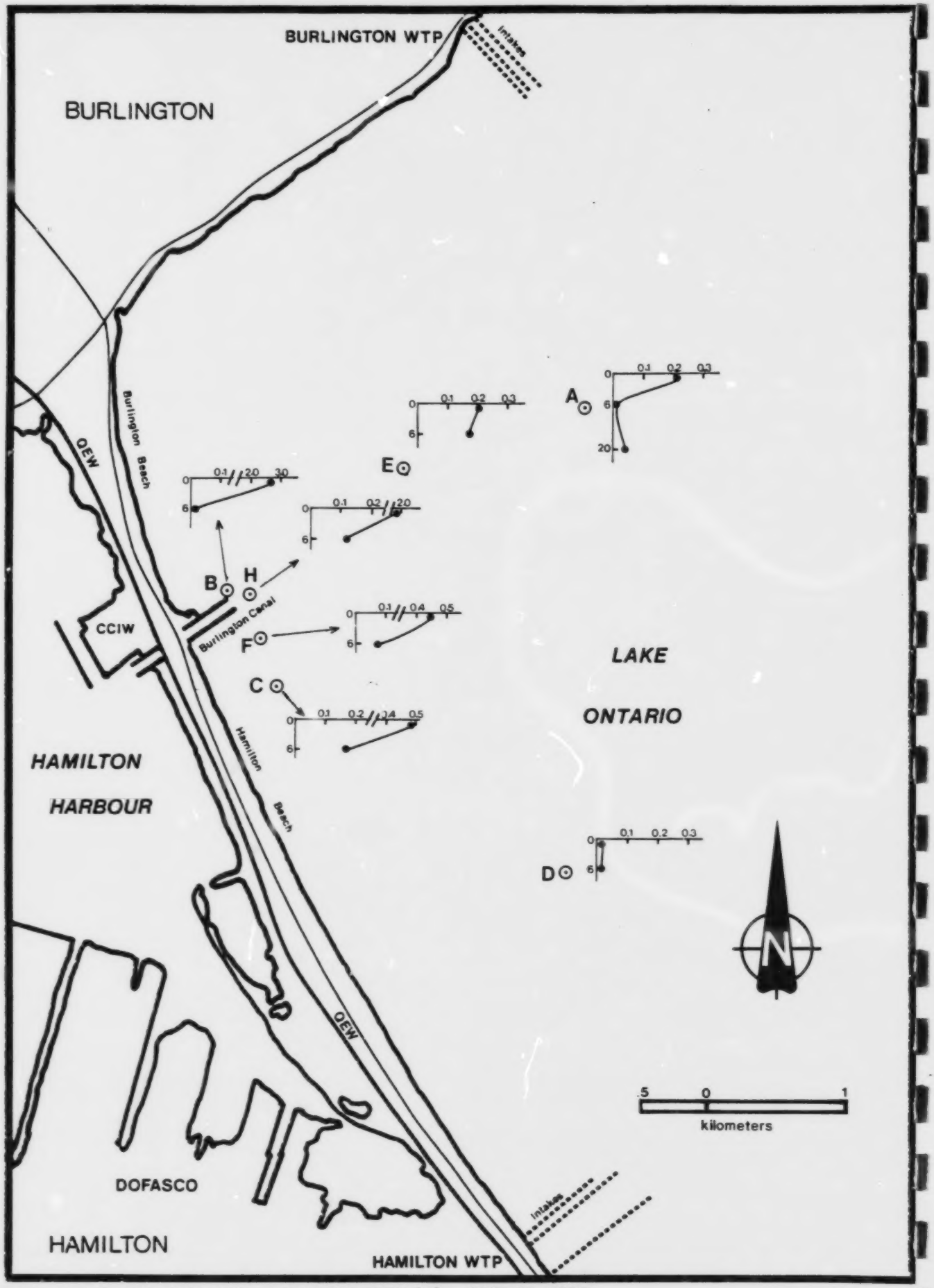

FIG 4.14: AMMONIA-N (mg/L) WITH DEPTH (m) JUNE 30, 1982

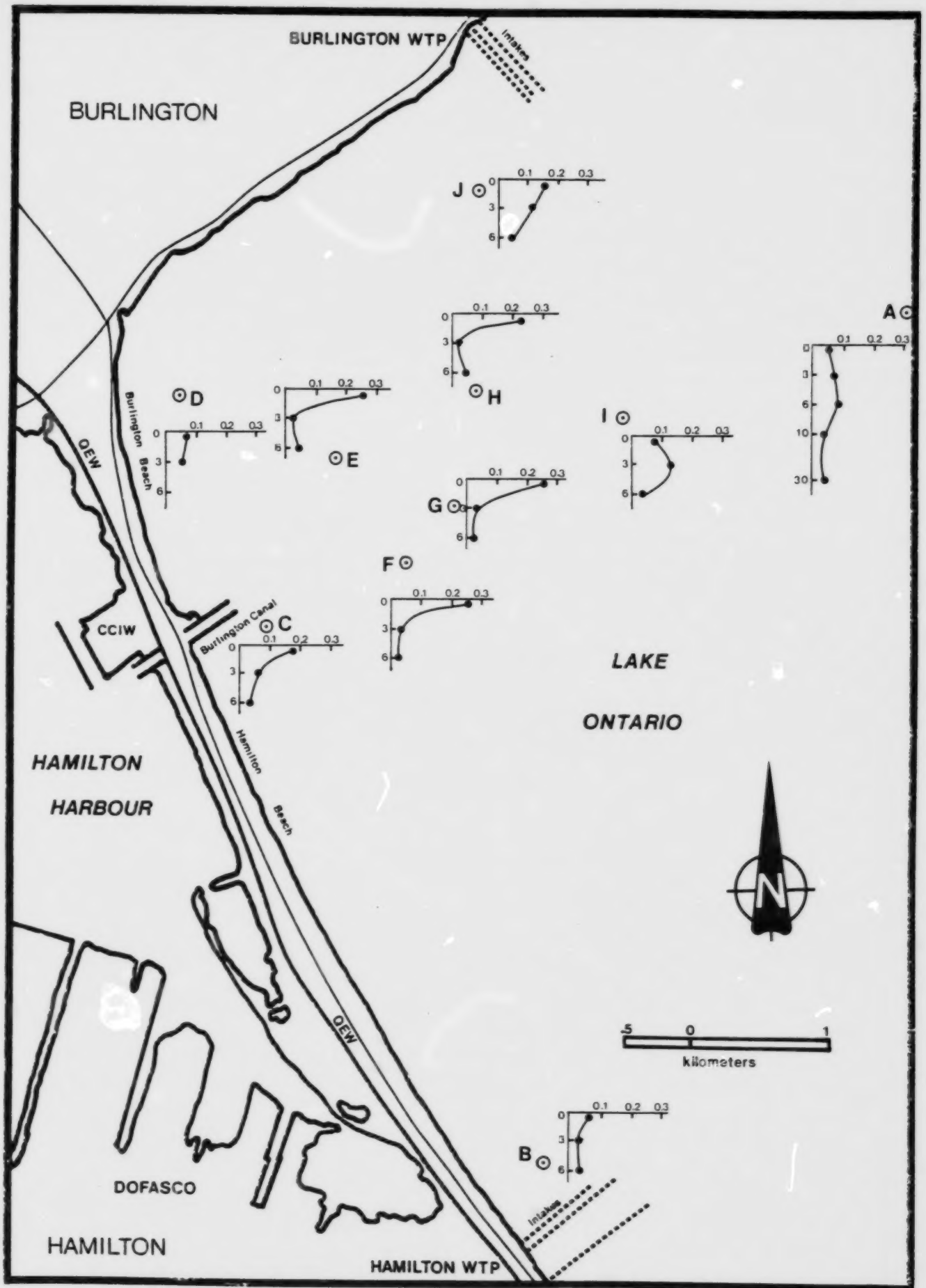

FIG 4.15: AMMONIA-N (mg/L) WITH DEPTH (m) AUGUST 24, 1982

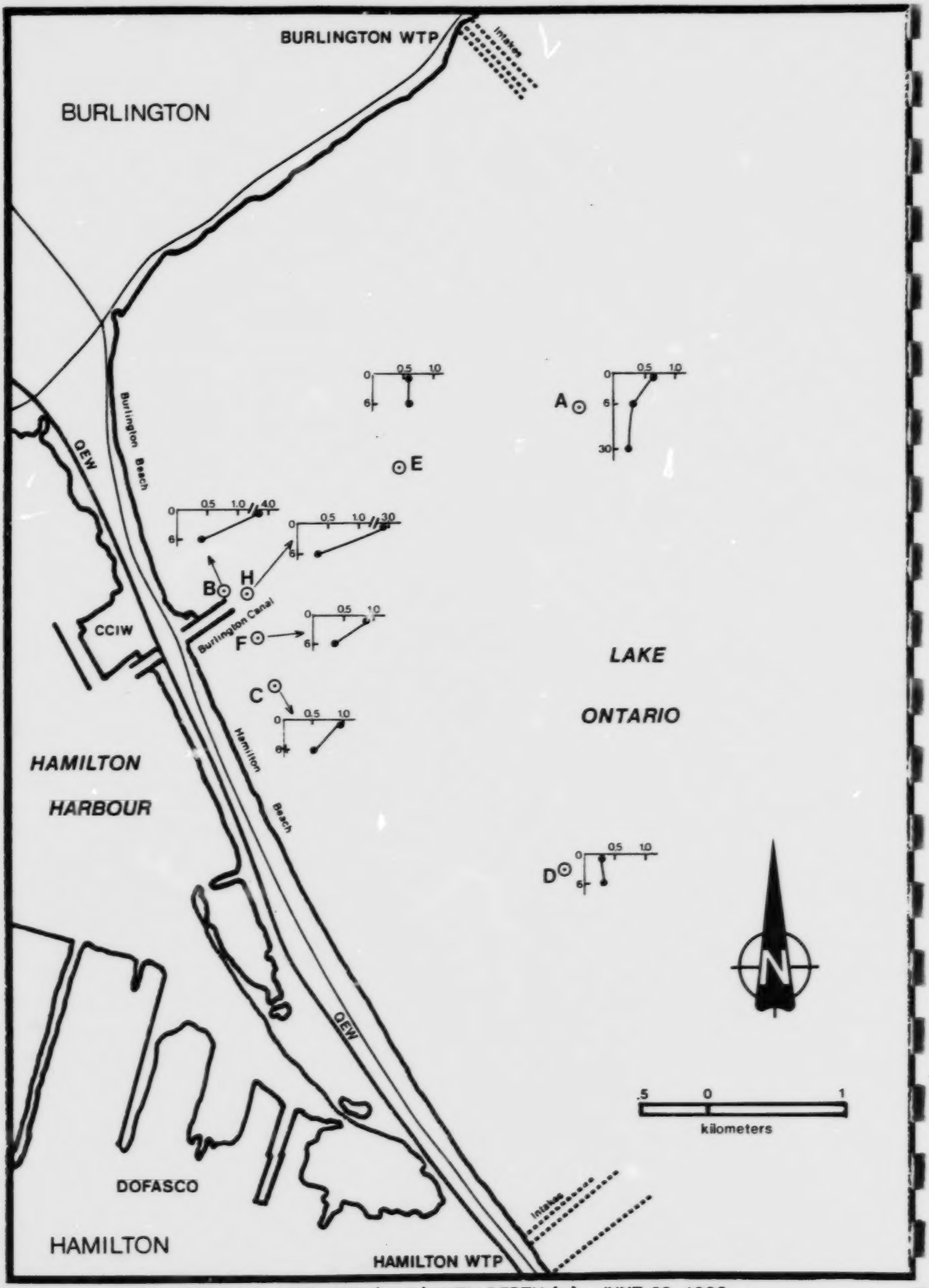

FIG.4.16 TOTAL KJELDAHL NITROGEN (mg/L) WITH DEPTH (m) JUNE 30, 1982

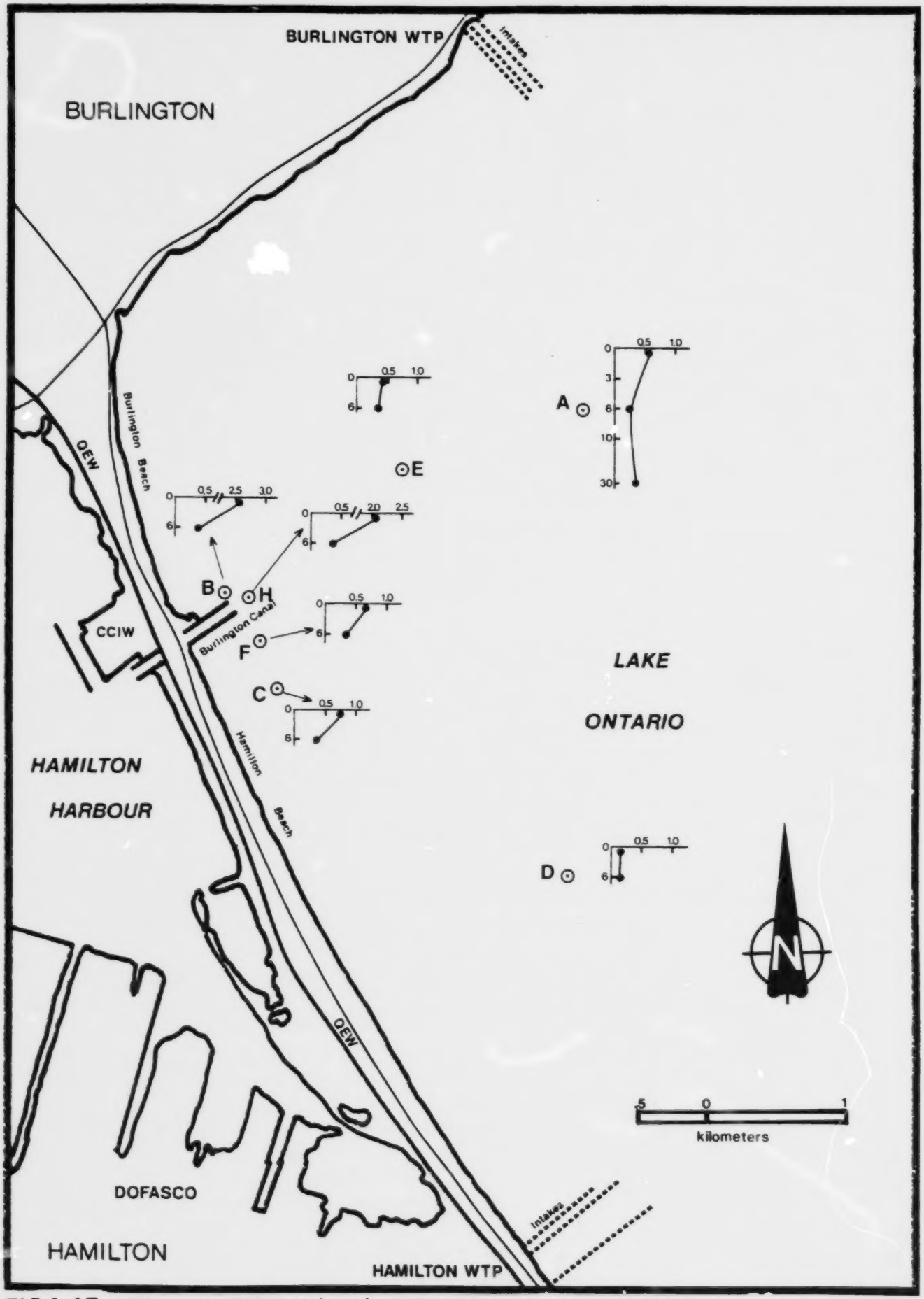

FIG4.17: NITRATE + NITRITE-N (mg/L) WITH DEPTH (m) JUNE 30,1982

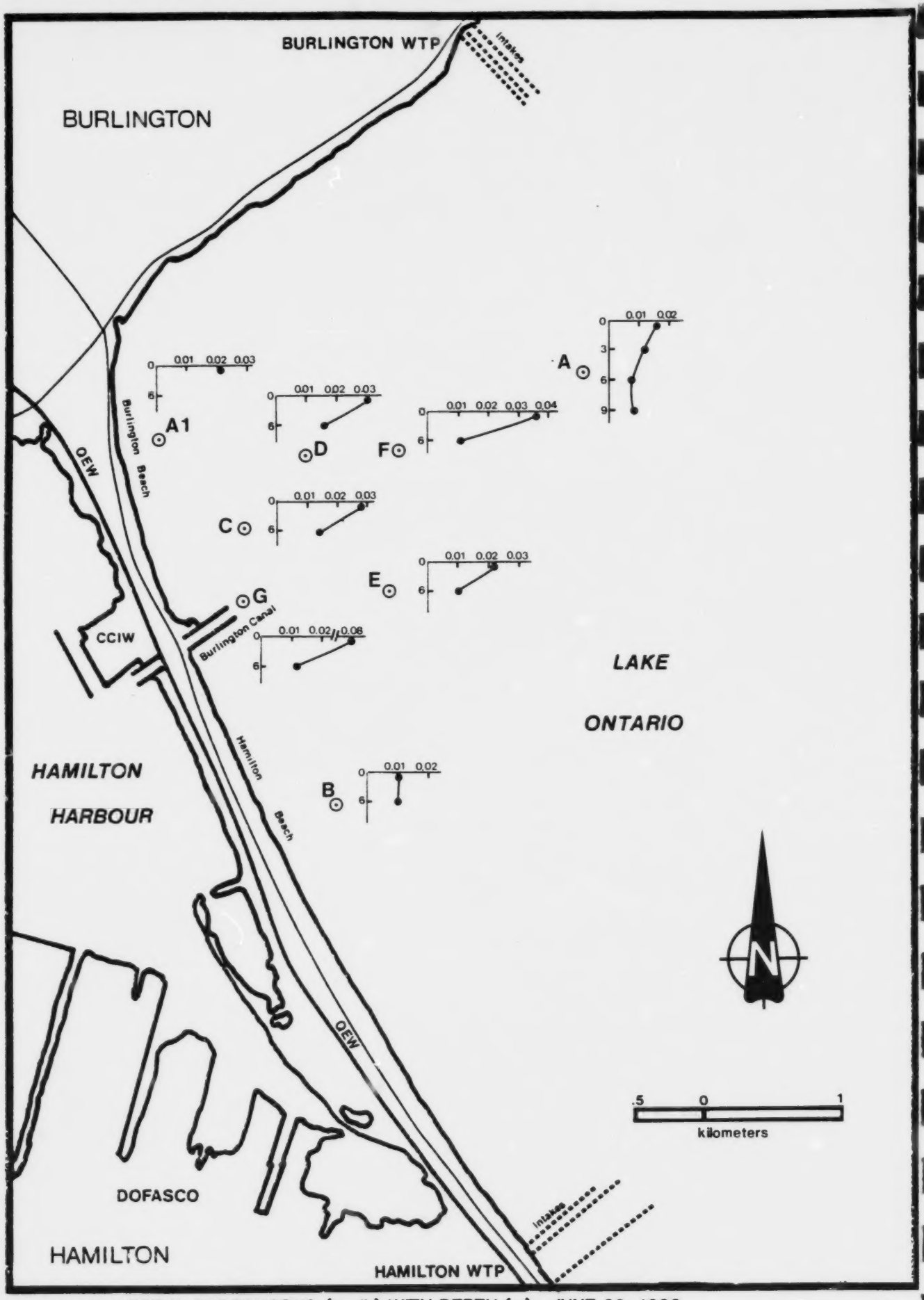

FIG.4.18 : TOTAL PHOSPHORUS (mg/L) WITH DEPTH (m) JUNE 29, 1982

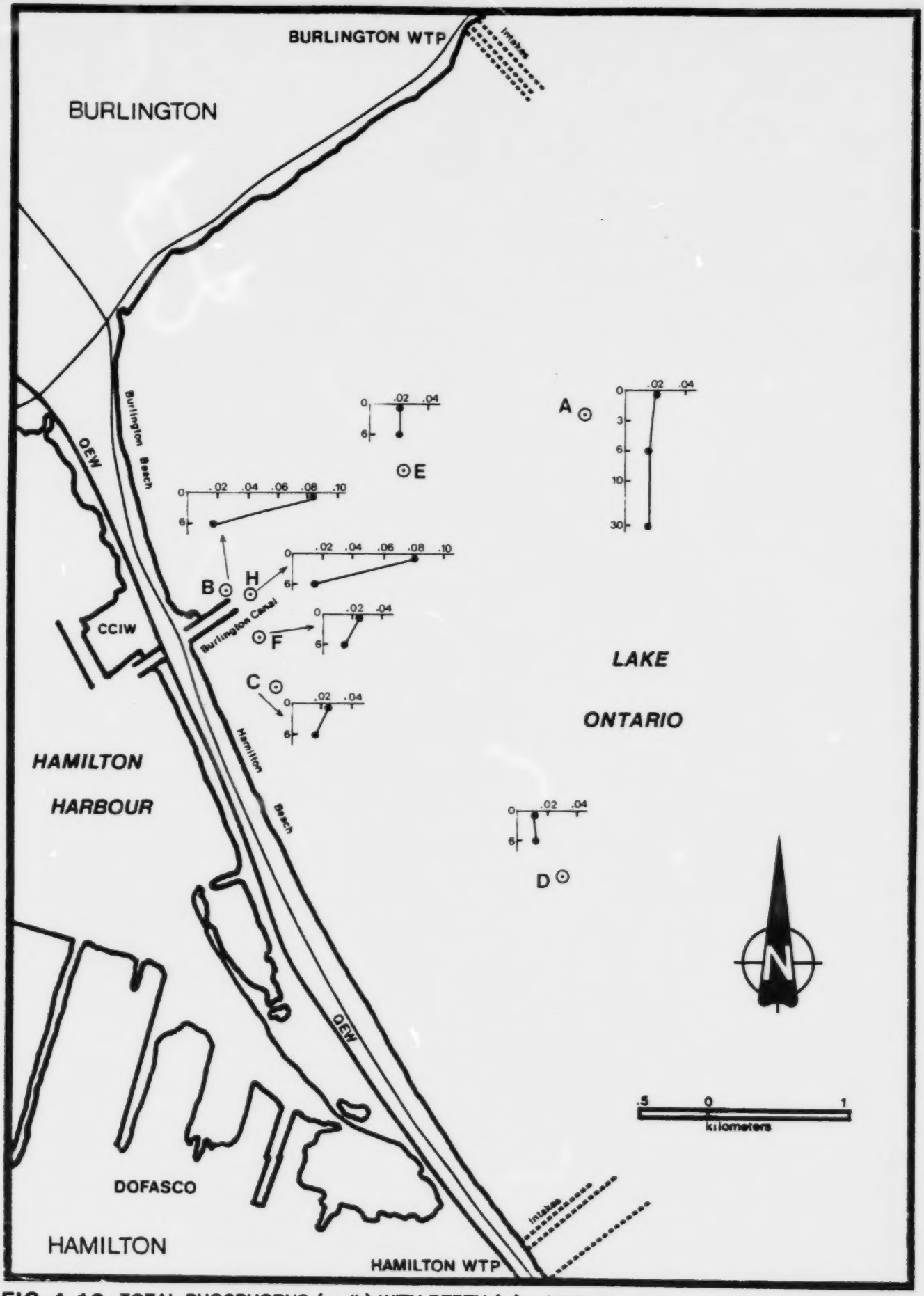

FIG 4.19: TOTAL PHOSPHORUS (mg/L) WITH DEPTH (m) JUNE 30, 1982

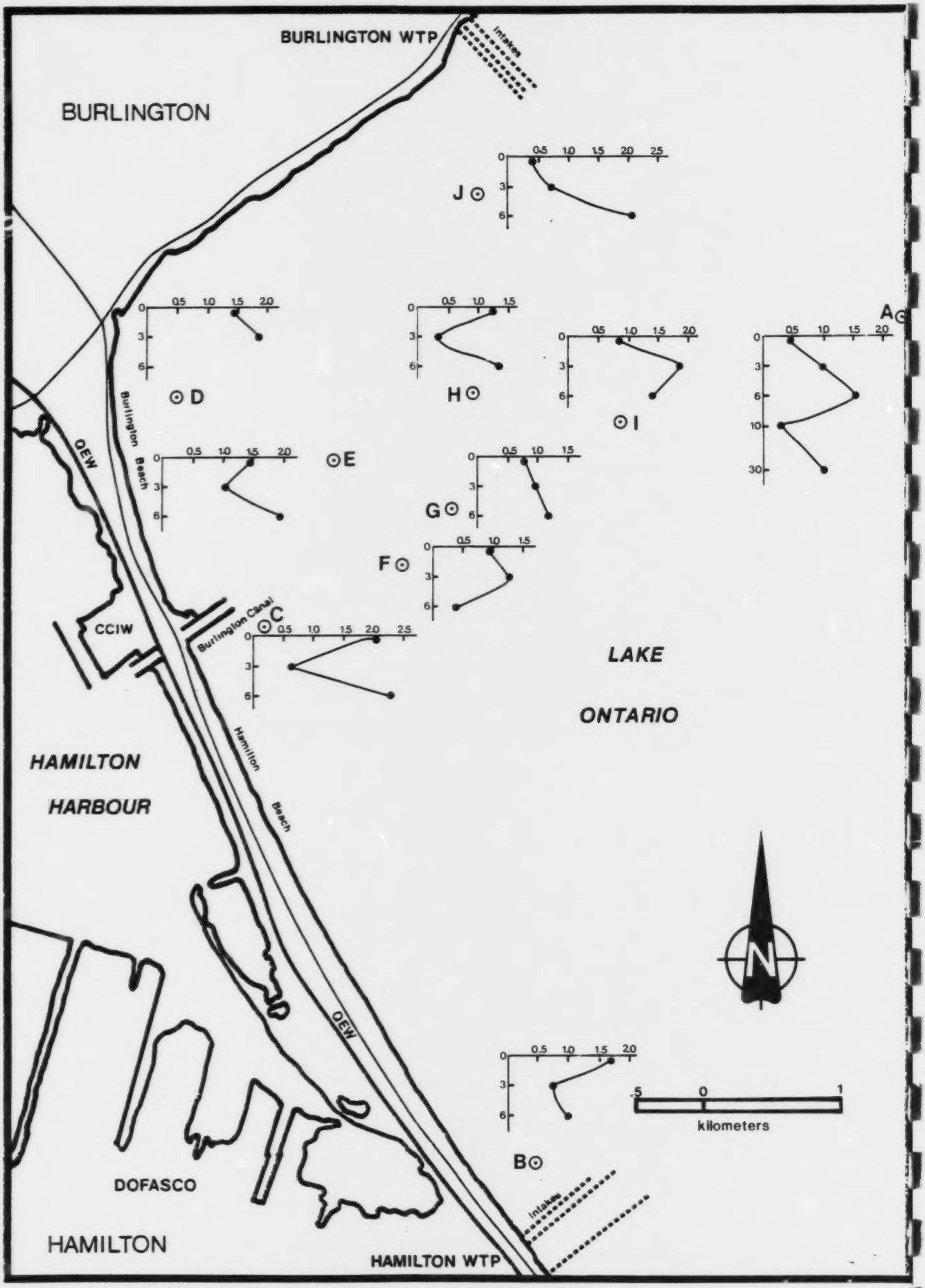

FIG. 4.20 : TURBIDITY (FTU) WITH DEPTH (m) AUGUST 24, 1982

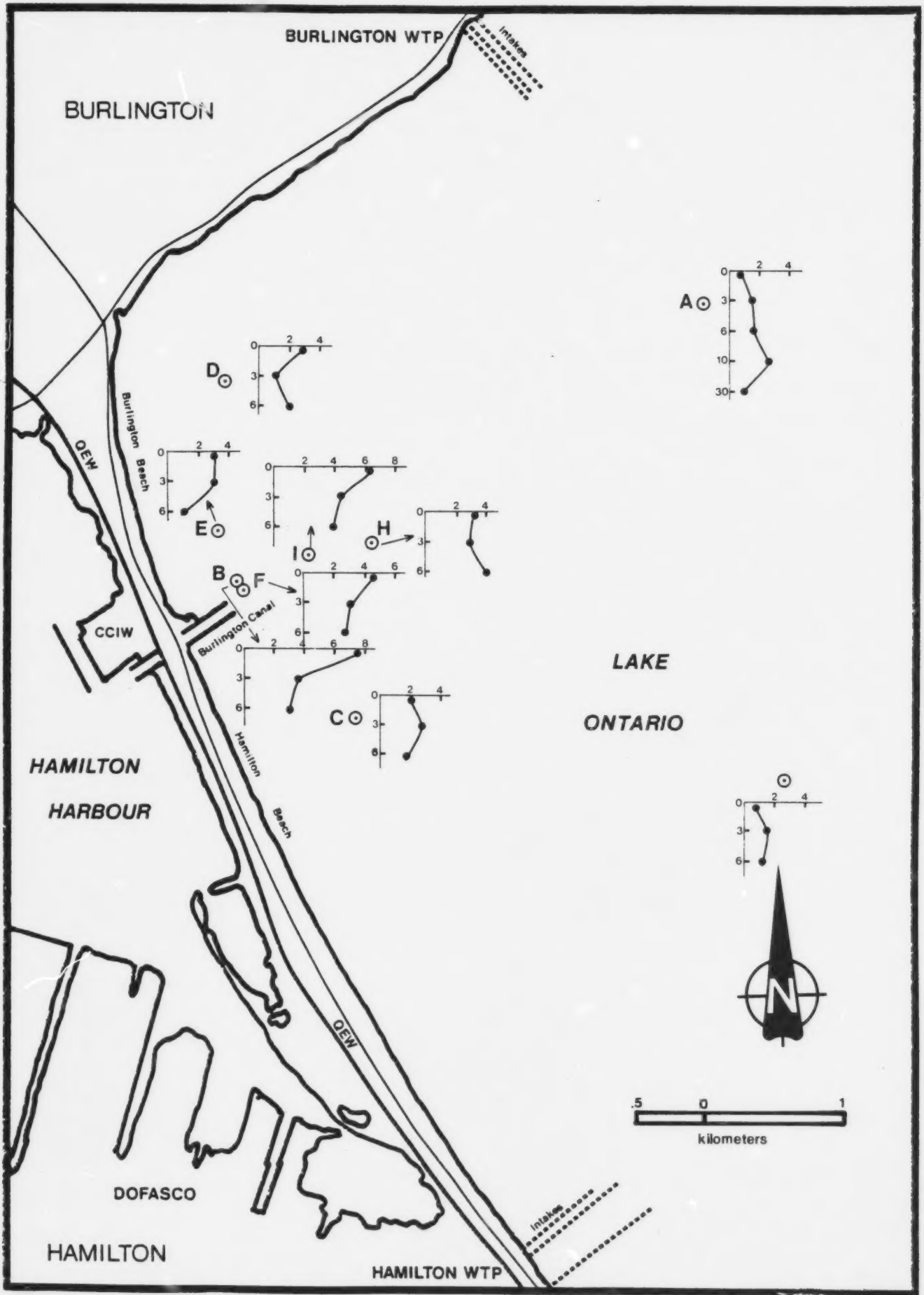

FIG.4.21 : TURBIDITY (FTU) WITH DEPTH (m) AUGUST 26, 1982

5.0 BENTHIC INVERTEBRATE ENUMERATION AND DETERMINATION OF THE MODE OF HEAVY METALS OCCURRENCE IN THE LAKEBED SEDIMENTS OF WESTERN LAKE ONTARIO.

5.1 Introduction

Investigations of the sediment quality and the distribution of benthic fauna in lake bottom sediments from the western end of Lake Ontario were carried out in late summer (August 22 - 24) of 1983. The National Water Research Institute (NWRI) located at the Canada Centre for Inland Waters (CCIW) performed the field work collection for the Ministry of the Environment (Great Lakes Section), and consultants at Barringer Magenta Limited were contracted to analyse samples and report their findings.

The purpose of this study was to determine speciation, spatial variation and diversity of benthic invertebrate communities inhabiting sediments in the Lake Ontario area adjacent to Hamilton Harbour, and to identify indicator organisms and their distribution in relation to their environment. Heavy metal determination and concentration in the sediments was another directive. Sequential extraction analysis was used to determine proportions of metals such as cadmium, copper, cobalt, chromium, iron, manganese, nickel, lead and zinc partitioned into exchangeable ions depending on combinations of "attack acids", or fractions.

This study also serves to update previous sediment and benthos studies done in 1964-65 (O.W.R.C., Johnson) and in 1972-73 (MOE), to determine any chemical and biological change temporally or spatially as a result of the domestic and industrial wastewater input to Hamilton Harbour.

Industries in Hamilton Harbour contribute a variety of materials in their wastewaters, including heavy metals such as zinc, cadmium, mercury, copper and lead. Input rates of these metals have been known to exceed the rate of natural introduction, subsequently accumulating in bottom sediments through precipitation and absorption. Benthic organisms inhabiting the sediments may then ingest these heavy metals which can occur in a variety of forms as adsorbates to clay minerals,

co-precipitates with the secondary iron-manganese oxides, diagenetic sulphides and carbonates and natural metal-organic complexes. Elevated levels of metals are found in sediments which are dominated by iron and manganese oxides and/or organic matter because of well-documented complexing ability and scavenging action of these geochemical phases.

5.2 Description of Study Area

Twenty-four of the total twenty-seven stations were sampled for benthic numeration and sediments in the western end of Lake Ontario, adjacent to Hamilton Harbour (see Figure 5.1). The remaining three stations sampled were located within the harbour. The lake and harbour are separated by the Burlington sandbar, and are linked together through the Burlington ship canal. Directional flow through the canal is variable due to temporal differences between the harbour and lake water levels. However, there is a greater flow to Lake Ontario from the harbour overall. During the summer it has been observed that warm harbour epilimnetic waters flow to the lake, while cold hypolimnetic lake waters flow back into the harbour. The lake current is generally considered to be counter-clockwise, although there is no fixed circulation pattern.

The Hamilton Harbour bed is made up of silt and clay sediments, which becomes more sandy in the area adjacent to the Burlington Ship Canal. This would indicate substantial currents at depths of up to 15 metres in that area. The lake bottom sediments are mainly comprised of coarse and fine sands up to 15 metres in depth. Silt and clay sediment predominate in the deeper areas in the Lake Ontario study area.

5.3 Field Procedure and Analytical Methods

5.3.1 Analysis of Heavy Metals

Sediment samples were collected by the NWRI for the Ministry of the Environment, at 24 stations (#360 to 383) located in the western end of Lake Ontario adjacent to Hamilton Harbour, and at one station within the harbour (#386). At stations 372 and 378, four box-core samples were collected from each station.

The wet sediment samples were first homogenized and a subsample obtained; then dried at 105°C to determine moisture content. Two duplicate 2-gram (dry weight) subsamples of the wet sediment were then analysed for cadmium, cobalt, chromium, copper, iron, manganese, nickel, lead and zinc. Duplicate samples were analysed since this proved to be a more reliable method. The duplicate matrix is more representative of the sample batch as a whole, and precision is calculated for a relatively large range of elemental concentrations. Data precision was calculated using Garrett's (1969) methods at the 95% confidence level. Trace element geochemical data typically demonstrate a log normal distribution, therefore all sample and replicate samples were transformed prior to calculation of precision. Analysis of variance (ANOVA) was carried out to examine differences in element concentrations between duplicate grab sample sites.

In a study of this nature, analytical accuracy proves somewhat difficult with data relating to partial extractions. Most certified reference material pertains to "total" metal measurements, probably due to the tighter precision obtainable between laboratories when they are using dissolution techniques for various metals.

Sequential chemical extraction was performed for speciation of particulate trace metals. This analysis partitions trace metals into five fractions likely to be affected by various environmental conditions: exchangeable, bound to carbonates, bound to iron-manganese oxides, bound to organic matter and residual metals.

Fraction 1 - Exchangeable Metal Ions

This is a measure of those trace metals which are released most readily into the environment. Sediment samples are agitated at room temperature continuously for 1 hour with 0.75 M LiCl + 0.25 M CsCl in 60% v/v methanol at pH 7, at room temperature. After centrifuging (4,000 rpm, 1 hr.) and decanting, the sample is rinsed with distilled water and re-centrifuged. Washing solution is then combined with the original extract and diluted to 20 mls. Concentrations of heavy metals are determined by atomic absorption spectrophotometer (A.A.S.) using a Varian Model AA-475 calibrated with standards made up in the same extract matrix.

Fraction 2 - Bound to Carbonates

It has been shown that significant trace metal concentrations are associated with sediment carbonates (Tessier et. al. 1979) making this fraction susceptible to changes in pH. The procedure involves agitation of the residue from Fraction 1 (as outlined above) for 1 hour with 10 mls of dilute HCl (pH 3) at room temperature. After centrifuging, washing and re-centrifuging with distilled water, the extract is analyzed for heavy metal content by A.A.S.

Fraction 3 - Bound to Iron-Manganese Oxides

Iron and Manganese oxides may occur as nodules, concretions or simply as a coating on particles. These oxides are good adherents for trace metals and are thermodynamically unstable under anoxic conditions. This method involves agitation of the residue from Fraction 2 with 10 mls of 0.1 M hydroxylamine hydrochloride (pH 2.5, HCl) for 6 hours at 96°C. The sample is then centrifuged, washed, re-centrifuged and analyzed for trace metals by A.A.S.

Fraction 4 - Bound to Organic Matter

Natural organic matter with its humic or fulvic acids is known to have complex and peptizing properties. Various forms of organic matter such as living organisms, detritus and coatings on mineral particles may bind with trace metals. These metals may be released as solubles under oxidizing conditions (Tessier et. al. 1979). The residue from Fraction 3 is digested with 3 mls of 0.02 M HNO_3 and 5 mls of 30% H_2O_2 (pH 2.0 with HNO_3) for 2 hours at 85°C with occasional agitation. An additional 3 mls of 30% H_2O_2 (pH 2, HNO_3) is then added and the extraction continued for 3 hours at 85°C with occasional agitation. After cooling, 5 mls of 3.2 M Ammonium Acetate in 20% (v/v) HNO_3 is added, the solution is diluted to 20 mls and agitated continuously for 30 minutes. After centrifuging, washing and re-centrifuging, the extract is analyzed for trace metals by A.A.S.

Fraction 5 - Residual Metals

This final procedure extracts mainly primary and secondary minerals possibly holding trace metals within their crystalline structure. These are the most tightly bound elements not usually released in solution under normal circumstances. The procedure involves digesting the Fraction 4 residue with a mixture of HF, $HClO_4$, and HNO_3 acids until near dryness. (If necessary, a second mixture of HF, $HClO_4$ and HNO_3 acids is to be added if a coloured residue is persistent.) An additional 1 ml $HClO_4$ is added and the solution evaporated until the appearance of white fumes. Finally, the residue is re-dissolved in concentrated HCl, and diluted to 20 mls for trace metals analysis by A.A.S.

The Control, Bulk, or Total Heavy Metal Analysis

Duplicate samples are analyzed for total heavy metal content using the methods outlined in Fraction 5. These results should be similar to the combined results of Fractions 1 to 5.

5.3.2 Enumeration of Benthic Invertebrate Communities

Forty-four benthic invertebrate samples were collected; including 19 duplicate grab samples and single grab samples (Figure 5.1). All samples were collected by NWRI personnel using a Shipek grab sampler. Samples were preserved with 10% formalin solution, and shipped to MOE's Toronto lab. Sorting was done in compliance with scientific fractional subsampling methods. The number of organisms present in the sample determined subsample dimensions (<200/subsample) . Subsequently, sorted organisms were identified to species level where possible using the current North American invertebrate taxonomic keys (see Table 5.1). A diversity index (described below) was derived for each sample and compared to the abiotic variables identified within the study area (see Figure 5.2 diversity index map).

5.3.3 Diversity Index

The diversity index is a measure of uncertainty as to which species a randomly selected individual will belong. This uncertainty or diversity is greater when there are more species. The Shannon-Weiner diversity index (Krebs 1978) was used to calculate diversity values.

$$\text{Diversity Index} = \sum_{i=1}^{s} (n_i/N \log_2 n_i/N)$$

Where S = number of species
Ni = number of individuals in each species
N = total number of individuals in the sample.

Clean water conditions are implied when the diversity index value is greater than three. Values of less than one are indicative of heavily polluted sediments. Moderately polluted conditions are evident when the index result is between 1 and 3 which predominates at the western end of Lake Ontario (Figure 5.2). The least polluted area with index values of >2.5 extended along the northwest shore from the canal mouth to Stations 361 and 362. Clean conditions were also found offshore from Confederation Park at Station 380. The remainder of the study

area appears to have an index between 1 and 2.5. Over all, the diversity index indicated an increase in the diversity of facultative benthos. This is probably a result of the abiotic characteristics of the depositional zone effected by the industrial and municipal discharges from Hamilton Harbour and urban surface drainage.

5.4 Discussion of Results

5.4.1 Distribution of Trace Metals in Bottom Sediments

Data reliability for all trace metal results was determined by performing ANOVA. For all metals, the F ratio proved to be below the critical value of 3.97 at the 95% significance level, thereby implying no difference between the first element determinations and the duplicate distributions. The data was therefore considered reliable.

Results of the sequential extract analysis showed fractions 1 to 3 to have poor precision for most trace metals because of concentrations measured just below or above detection limits (Table 5.2). In Table 5.3, fractions 4, 5 and total metals demonstrated several sampling sites with anomalous metal results (defined by mean plus 1 standard deviation per percentile) (Figures 5.3 to 5.5).

In comparing contoured total metal results (Figure 5.5), with the depth contours of the study area (Figure 5.1) higher concentrations of metals clearly follows what appears to be a lakebed embayment or dredged channel towards the Burlington Ship Canal mouth. Levels of trace metals, with the exception of manganese, clearly increased with greater water depth (Tables 5.4 to 5.6). Figures 5.6 to 5.13 illustrate contoured metal concentrations in the study area. Iron and chromium levels appeared elevated at Station 379; a nearshore area close to Confederation Park (Figure 5.6 and 5.7). High levels of manganese occurred in both deep and nearshore water sites, particularly in a defined narrow belt situated along the northwest side of Lake Ontario (Figure 5.8).

Trace metal associations are confirmed by using coefficients forming correlation matrices (Tables 5.7 to 5.9). The results are outlined below.

Total metal:	Ni, Cr, Cu, Pb, Zn	strong association (coefficient >0.8)
Fraction 5:	Cu, Fe, Pb, Zn	
Fraction 4:	Cd, Cu, Pb, Zn	(Cd may be misleading here because values are close to detection level)

Clearly, Cr, Cu, Ni, Pb, and Zn reflect strong interrelationships in the deeper water sediments.

5.4.2 Sequential Extract Distribution Results of Metals in Lake Bottom Sediments

Tables 5.10 - 5.18 show the proportions of metals freed by the five extraction reagents, and the percentage difference between the total stepwise and bulk fraction results. All values represent the mean content of the two analyses for duplicate samples. Trace element values close to detection levels may hinder precision of extraction percentages and therefore results would not be statistically relevant.

Most metals including, cadmium, chromium, copper, nickel, lead, iron and manganese, are distributed mainly in fractions 4 (organically bound) and 5 (silicate bound). These results imply that the metals are predominantly in non-labile form and would therefore be unavailable for bioaccumulation by benthic organisms. However, there are some sample sites where sediments do release a proportion of trace elements into the ion exchangeable - weakly bound fraction 1. These sites are identified in Table 5.19. It appears that those samples having a higher proportion of weakly bound metals also have a higher residual (fraction 5) and total bulk metal content.

5.4.3 Sediment Core Sample Results

Lake sediment core samples were taken at stations #372 and #378 (Figure 5.1) and sequential extraction analysis was applied. Resultant graphs of total bulk metal concentrations are found in figures 5.14 and 5.15 for copper, lead, chromium and manganese. Other metals such as cadmium, iron, nickel and zinc not shown on the graph, demonstrated similar distributions. Cobalt values were at or below the detection level, and therefore were not included in the graphs.

The core taken at Station 372 demonstrated that fractions 4 and 5 contain more than 95% of all trace metals indicating the non-labile nature of the sediment. In the upper 5 cm of the core, all trace metals were enriched slightly compared to immediately beneath this level. Concentrations of all metals are reduced until the 16 cm depth profile level where a dramatic increase is seen, particularly for copper and zinc in the bulk sample results. A higher proportion of chromium, copper, manganese, nickel, iron and zinc is distributed in fraction 4 at 16 cm depth when compared to fraction 5 results. Metal content tended to decrease after 16 cm, then resumed a consistent level below 30 cm depth as shown in Figure 5.14 for bulk results.

At Station 378 as in Station 372, core metal concentrations were highest within the top 5 cm. A slight increase occurred at 10 cm depth for all trace elements, then decreased abruptly to 14 cm with the exception of manganese which increased at 14 cm, and then slightly decreased to 40 cm depth (Figure 5.15). Lead, copper and chromium all followed a zigzag pattern with an increase in concentrations at 16 cm, a decrease at 25 cm, another increase at 30 cm and followed by a slight decrease to 40 cm depth. The sequential extraction data again indicated that 95% of the metal content was found in fractions 4 and 5; however, over 29% of manganese occurred in fraction 3 of the top 1 cm of the core sample.

Partitioning results of trace metals in both cores show abundant concentrations in fractions 4 and 5. This suggests that the vertical metal variations are of physical sediment composition, rather than chemical redistributions due to diagenesis. The dramatic increase of metals in core 372 at 16 cm depth indicates a major metal-rich discharge to sediments, probably from Hamilton Harbour via the Burlington ship canal. Turbulence caused by dredging activities could have increased the movement of contaminated sediment away from the canal.

The practice of depositing dredge material from Hamilton Harbour into western Lake Ontario was discontinued after 1945. Prior to this time, the steel industries were undoubtedly running at peak production in the war effort, with little concern for heavy metals released into the environment. Based on an approximate constant sedimentation rate of 2 mm/yr the large deposit of trace metals occurred about 70-80 years ago. This of course is highly speculative since no scientific dating of the sediments was done. Clearly, more study is necessary on historical sedimentation rates and sediment mineralogy in order to determine the source of this metal-rich deposit at 16 cm, and at the top of the sediment cores in both sample locations.

5.4.4 Comparison of Trace Metals in Bottom Sediments and Recommended Guidelines For Elements in Dredge Spoils

Table 5.20 outlines those stations whose samples exhibited contaminated sediments in excess of MOE guidelines for open water dredged sediment disposal. High levels of iron and chromium loadings were reflected by the distribution of both berthic invertebrates and metal concentrations in bottom sediments, probably a result of Hamilton Harbour's heavy industrial activities.

5.4.5 Relationship Between Diversity Index, Depth, Substrate Type and Heavy Metals Distribution

Table 5.21 outlines depth, substrate type and diversity index for station samples. As previously noted the diversity index is the measure of uncertainty as to which species a randomly selected individual will belong to. The diversity or uncertainty is greater when there is a larger number of species with similar numbers of individuals between them. Diversity index calculation and results are found in Section 5.3.3. In general, the diversity index suggests the study area to be moderately polluted with the most contaminated areas at several points near the Burlington Ship Canal as well as one or two deep water locations (diversity index <2) (Figure 5.2).

The distribution of heavy metals in lake bottom sediments, the distribution of benthic organisms, depth and substrate type are clearly inter-related. An analysis of variance (ANOVA) was run on sample sites divided into groups based on factors as depth, presence or absence of diagnostic benthic organisms, total density of worms and nickel-lead pollutant results to closely examine the exact nature of this relationship. The analysis determined if a significant difference was evident or not, for all variables. For example, variables such as copper-fraction 5 and total copper, depth and number of invertebrates for each species were used. Only fraction 5 and total metal results were utilized since the concentrations of metals in sequential extracts 1 to 4 were often below instrument detection levels.

Depth proved to be a significant factor in abundance and distribution of trace metals and benthos. In Table 5.22 indicator species (Pisidium casertanum, Sphaerium nitidum, Micropsectra sp, Chironomus (Chironomus) thummi (riparius), Pontoporeia sp. and Lumbricus Variegatus, most of the metals, and diversity indices demonstrated obvious differences when sites were subdivided on the basis of depth (shallow versus deep). It is clear that heavy metal abundance and the distribution of benthic organisms are dependent on lake depth.

5.4.6 Distribution of Benthic Invertebrates Communities

A total of 43 benthic species constituted the benthic macroinvertebrate community within the western end of Lake Ontario. Dominant groups include: Oligochaeta, Tubificidae, Bivalvia Sphaeriidae and Amphipoda (see Table 5.23). Actual population results may be found in Appendix A for each station.

Oligotrophic indicator species identified were Sphaerium nitidum (Figure 5.16) and Pisidium conventus of the Bivalvia Sphaeriidae taxa group which are typical of deep, cool, aerated waters. These invertebrates were present, but not in great numbers. P. conventus was found in a depth range of 10 to 20 metres, whereas peak densities usually occur in depths of 25 to 30 metres. For this area P. conventus may be a relict species. Although Sphaerium nitidum is similar to P. conventus, it is not indicative of trophic conditions. Typically, S. nitidum inhabits mesotrophic environments in colder, profundal areas of lakes, with adequate dissolved oxygen levels. It was observed in two general areas, one small area in the northeast and a larger zone from the Burlington ship canal, extending southeast (Figure 5.16). The greatest population densities were found in the northeast group at Station 361 (291/m^2) and the lowest densities inhabited the Burlington ship canal. Adequate dissolved oxygen, current and water temperatures necessary for survival were available in these inhabited areas; however, conditions may not be as ideal as expected since estimated peak values of 1500-2000/m^2 were not reached.

The only other oligotrophic species found was Pontoporeia (Figure 5.17) which normally inhabits deep, cold lakebeds. This species is able to survive depths of up to 300 m with oxygen saturation levels of less than 7 percent. In the study area Pontoporeia were ubiquitous and most were female. Characteristically, maximum densities of this species were observed in the deeper depositional areas of Lake Ontario. Smaller populations were identified within Hamilton Harbour at Station 386. In a previous 1974 study of Hamilton Harbour conducted by the Ministry of the Environment, Pontoporeia spp. was not found.

Pisidium casertanum (Figure 5.18) generally inhabits a moderately enriched environment; however, densities may be as great in oligotrophic areas. This species' productivity is usually dependent on other factors as hardness and pH. In Figure 5.16 it is evident that P. casertanum maximum densities occurred in two general areas of variable substrate, but similar in depth and possibly in water quality. Other sphaeriid species found within the study area were also of some value in interpreting environmental conditions; however, their distribution was too sparce to draw any concrete ecological conclusions. All were observed in moderately enriched to clean areas.

Chironomidea taxa were found to be eurybathic and tended to inhabit those areas typically high in oligochaeta populations. Micropsectra and Procladius (Figure 5.19), were the prevailing species, and both considered indicative of mesotrophic to eutrophic environments. In eutrophic lakes, Procladius sp. is an important ooze predator and usually has no substrate preference. Micropsectra spp. have been known to inhabit Lake Erie (eastern basin) and Ontario in deep to intermediate depths. It has also been associated with Heterotrisoocladius subpilosus. In this study, its distribution was discovered to cover almost the entire area with absences only at the deepest stations and a few at very shallow depths close to shore.

Another Chironomidea species, Chironomus (c) reparius frequented nearshore stations. Characteristically, this species fluorishes in low dissolved oxygen levels and organically polluted habitats. The remainder, the midges (Chironomidae), were sparsely distributed, but favoured the nearshore shallow waters. Several factors determine distribution patterns and abundance of chironomids as substrate type (i.e. stability, particle size), pH (i.e. acidification, nutrient loading), gaseous equilibrium of the water (oxygen demand) and food supply.

The taxonomic group, Oligochaeta, had the highest density and diversity in western Lake Ontario, particularly at the Burlington Ship Canal outflow. Tubificidae had the highest relative percentage compared to other Oligochaeta families; Lumbriculidae and Naididae. The dominant tubificid species was Limnodrilus hoffmeisteri (Figure 5.20). Most

tubificids identified were immature non-capilliform species. In past studies of Hamilton Harbour and the adjacent area in western Lake Ontario, Limnodrilus hoffmeisteri has been often identified (Johnson & Matheson, 1968, McLarty, MOE pers. comm.). Since this species is very tolerant of organic pollution, it is common to all types of environments, often appearing in great numbers in polluted areas. L. hoffmeisteri, on the other hand, is very sensitive to inorganic pollutants and are not able to tolerate ions as copper, lead, and arsenic in their habitat (Kennedy, 1965). The worm population density remained the highest in the deeper zones of the study as did the heavy metals in the sediment. The majority of trace metal concentrations were not, however, in labile form, therefore reducing bioavailability.

Tubifex Tubifex, also a member of the Oligochaeta family, was found mainly in the deep areas as was Limnodrilus spp. and Peloscolex spp. T. Tubifex has generally low density and sparse distribution and was located predominantly at Station 386 in Hamilton Harbour, and from the Burlington Ship Canal out into the depositional zone in Lake Ontario at Stations 368, 367 and 364. The canal had the greatest density ($2203/m^2$) of T. tubifex at Station 370. In 1970, Brinkhurst discovered this species in Hamilton Harbour in depths less than 12 m adjacent to the heavily industrialized site. Towards the deep central part of the harbour species density increased with depth, thus contributing as much as 56 percent of all oligochaetes including the harbour, and adjacent Lake Ontario (Brinkhurst, 1970). Brinkhurst further concluded that T. tubifex and Limnodrilus hoffmeisteri were species most resistant to organic and inert mineral pollution.

Lumbricus variegatus (Figure 5.21), another species of the worm family found in the study area, has also been identified in Lake Superior, the Niagara, St. Clair, St. Marys and St. Lawrence Rivers, in Humber Bay of Lake Ontario and in Northern Ontario's acid stressed lakes. The distribution of this species in western Lake Ontario was mainly concentrated near the Burlington Ship Canal extending northeast to Stations 363 and 378. The maximum density was $5683/m^2$ found at Section 367. A small isolated high density area at Station 382 was observed also. L. variegatus tended to favour greater depths, since populations were not found at the 5 m sandy littoral stations.

Asellidae and Hirudinea taxonomic groups were also found to be inhabiting the study area. Asellus racovitzai racovitzai of the Asellidae taxa family, was sparcely distributed in generally shallow areas. This species has been noted throughout the Great Lakes drainage basin and is often affiliated with organically enriched environments. Helobdella stagnalis and Piscicola species of the Hirudinea family, were detected but in numbers so small that any distinctive distribution pattern could not be distinguished for the study area. However, since H. stagnalis consumes oligochaetes, it could be expected to inhabit areas of high oligochaete densities such as Station 367.

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TABLE 5.1

TAXA	LEVEL OF PRECISION	TAXONOMIC REFERENCE
Isopoda	to species	Williams (1976) Pennak (1978)
Amphipoda	to species	Bousefield (1958) Holsinger (1976) Pennak (1978)
Decapoda	to species	Crocker & Barr (1968) Hobbs (1976) Pennak (1978)
Molluska	to species	Harmen & Berg (1971) Clarke (1973) Burch (1974) Pennak (1978)
Hirudinea	to species where possible, otherwise to genus	Sawyer (1972)
Oligochaeta	to species, if organisms are mature, otherwise to genus	Brinkhurst & Jamieson (1971)
Insecta	to species where possible, otherwise to genus	Usinger (1956) Johannsen (1969) Edmunds, et al. (1976) Wiggins (1977) Merritt & Cummins (1978) Oliver, et al. (1978) Pennak (1978) Seidl, et al. (1980) Simpson & Bode (1980)

TABLE 5.2: Analytical Precision at 95% Confidence Level Based on Calculation from 50 Replicate Samples

	FRACTIONS					
Element	#1	#2	#3	#4	#5	#6
Cd	+	+	+	+	+	20
Co	+	+	+	+	+	10
Cr	+	+	+	26	2.8	5.5
Cu	+	+	+	4.0	6.8	2.9
Fe	32	8.5	13.4	2.8	0.9	0.7
Mn	3.4	25.6	4.2	1.7	25.1	0.7
Ni	+	+	+	3.7	11.8	11.2
Pb	+	+	+	11.7	8.0	8.3
Zn	+	+	+	4.7	7.1	2.7

\+ Insufficient values above detection level to reliably estimate precision.

#1 - 0.75 M LiCl + 0.25 M CsCl in 60% methanol at pH 7
#2 - 10% HCl (pH 3)
#3 - 0.1 M Hydroxylamine Hydrochloride
#4 - 0.02 M HNO_3 + 30% H_2O_2 (pH 2)
#5 - HF-$HClO_4$-HNO_3 on residue
#6 - HF-$HClO_4$-HNO_3 on bulk sample

TABLE 5.3: Summary of Element Statistics Calculated from Mean (4) Element Abundances in 22 Bottom Samples (All Values are in ppm)

Element	Fraction 4		Fraction 5		Total Metal		Avg. Metal Conc. Draining in L. Ont.
	M	S	M	S	M	S	M
Cd	+	+	0.3	0.19	1.1	0.8	NA
Co	+	+	3.5	2.4	3.9	2.5	NA
Cr	9.7	1.6	63.7	21.7	70.8	33.7	30.5
Cu	12	9	18.7	12.0	33.2	23.2	34.0
Fe	353	97	27880	8956	30270	4639	3.1%
Mn	228	96	542.5	200	919	270	1060
Ni	1.6	1.9	18	8.3	20.3	11.2	50.0
Pb	9	7	28	21	42	31	26.0
Zn	30	23	101	47	138	79	95.0

+ Insufficient values above detection level in fraction to determine statistics.

NA Not Available
1. From O.G.S. publication.

TABLE 5.4: Classification of Sample Site Demonstrating Metal Enhancement Exceeding Mean + 1 Standard Deviation (values summarized on Table 3) in Fraction 4

Sample Site	Depth M	Sub. Type	Cr	Cu	Fe	Mn	Ni	Pb	Zn
361	9	S	+	+			+		+
363	19	L	+				+		
364	31	L	+	+				+	+
367	15	L	+						
368	20	L	+						
372	2	L	+						
375	10	D			+				
376	15	D			+				
379	5	S			+				
380	10	S				+			
382	10	L			+	+			
383	30	L	+	+		+	+	+	

Substrate Type S = Sand
L = Silt Clay
D = Silt Sand

Sub. Type = Substrate Type

TABLE 5.5: Classification of Sample Site Demonstrating Metal Enhancement Exceeding Mean + 1 Standard Deviation (values summarized on Table 3) in Fraction 5

Sample Site	Depth M	Sub. Type	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
361	9	S	+		+	+			+	+	+
363	10	L							+	+	
364	31	L	+		+	+			+	+	+
368	20	L								+	
370	11	S		+							
372	2	L							+	+	
379	5	S					+	+			
382	10	L						+			
383	30	L	+	+	+	+	+	+	+	+	+

Substrate Type S = Sand
L = Silt Clay
D = Silt Sand

Sub. Type = Substrate Type

TABLE 5.6: Classification of Sample Site Demonstrating Metal Enhancement Exceeding Mean + 1 Standard Deviation (values summarized on Table 3) for Total Metals

Sample Site	Depth M	Sub. Type	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
360	4	S						+			
361	9	S			+	+			+	+	
363	19	L				+			+	+	
364	31	L	+	+	+	+			+	+	+
365	4.5	S					+	+			
372	2	L		+							
379	5	S			+		+				
380	10	S	+			+					
383	30	L		+		+			+	+	+

Substrate Type S = Sand
L = Silt Clay
D = Silt Sand

Sub. Type = Substrate Type

Table 5.7 Correlation Coefficient Matrix for Metals in #4 Fraction

	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Cd	0								
Co	0.03	-0							
Cr	0.4	-0.36	0						
Cu	0.93	-0.05	-0.03	0					
Fe	-0.08	-0.55	0.32	0.30	0				
Mn	0.58	-0.09	0.36	0.38	0.59	0			
Ni	0.59	0.46	-0.04	0.71	0.04	0.42	0		
Pb	0.90	0.55	-0.26	0.92	-0.26	0.44	0.70	0	
Zn	0.80	0.09	0.04	0.76	0.20	0.33	0.26	0.67	0

TABLE 5.8: Correlation Coefficient Matrix for Metals in #5 Fraction.

	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Cd	0								
Co	0.40	-0							
Cr	0.03	-0.76	0						
Cu	0.5	-0.25	-0.33	0					
Fe	-0.30	-0.33	0.35	0.79	0				
Mn	0.56	-0.14	0.17	0.80	0.35	0			
Ni	0.44	0.19	-0.15	0.34	0.22	0.79	0		
Pb	0.31	0.37	-0.44	0.81	0.97	0.39	-0.19	0	
Zn	0.17	0.37	0.49	0.69	0.95	0.18	0.39	0.96	0

Raw element data log transformed
No. of Samples = 22

TABLE 5.9: Correlation Coefficient Matrix for Metals for Total Metals (Bulk Samples).

	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Cd	0								
Co	0.37	-0							
Cr	0.61	-0.41	0						
Cu	0.57	-0.35	-0.91	0					
Fe	-0.29	-0.25	0.77	0.48	0				
Mn	-0.14	0.13	0.37	0.16	0.72	0			
Ni	0.62	0.47	0.94	0.97	0.55	0.18	0		
Pb	0.62	0.37	-0.84	0.96	0.34	0.10	0.95	0	
Zn	0.60	0.48	0.90	0.98	0.46	0.13	0.97	0.96	0

TABLE 5.10: Distribution of Cd in sequential extracts 1-5. All values are in %. Col. 6 represents % difference between 1-5 total and bulk value.

Sample No.	#1	#2	#3	#4	#5	%D
360	0	0	0	23.1	76.9	30.3
361	0	0	0	82.2	17.8	14.2
363	6.1	0	0	93.8	0	12.0
364	0	0	0	74.0	26.0	24.0
365	0	0	0	18.4	81.6	2.8
366	0	0	0	44.4	55.5	9.3
367	0	0	0	100.0	0	55.0
368	0	0	0	44.4	55.5	11.3
369	0	0	0	0	0	0
370	0	0	0	54.6	45.4	45.0
371	0	0	0	100.0	0	50.0
372	0	0	0	100.0	0	54.0
373	0	0	0	100.0	0	33.0
374	0	0	0	100.0	0	84.0
375	91.4	0	0	8.6	0	2.0
376	42.1	0	0	57.9	0	80.0
377	0	0	0	100.0	0	88.0
379	0	0	0	13.0	87.0	34.0
380	0	0	0	33.0	67.0	100.0
381	0	0	0	45.2	54.6	100.0
382	0	0	0	50.0	50.0	100.0
383	0	0	0	100.0	0	41.0

TABLE 5.11: Distribution of Co in sequential extracts. All values are in %. Col. 6 represents % difference between 1-5 total and bulk value.

Sample No.	#1	#2	#3	#4	#5	%D
360	0	0	11.0	0	89.0	-13.0
361	0	0	13.0	0	87.0	8.0
363	0	0	0	0	100.0	25.0
364	9.4	0	10.4	7.3	72.9	100.0
365	0	0	0	0	100.0	-22.5
366	0	0	0	44.4	100.0	17.0
367	0	0	0		100.0	-50.0
368	0	0	26.8	0	73.2	-37.0
369	0	0	0	0	100.00	0
370	0	0	0	0	100.0	29.0
371	0	0	0	0	100.0	17.0
372	0	0	0	0	100.0	50.0
373	0	0	18.0	0	83.0	40.0
374	0	0	30.0	20.0	50.0	-100.0
375	0	0	36.0	22.0	42.0	-140.0
376	0	0	33.0	21.0	45.0	-120.0
377	0	0	26.0	11.0	64.0	53.0
379	0	0	39.0	9.0	53.0	-90.0
380	0	0	0	79.0	71.0	-40.0
381	0	0	0	0	100.0	50.0
382	0	0	0	0	100.0	0
383	5.0	0	0	5.0	90.0	9.1

TABLE 5.12: Distribution of Cr in sequential extracts. All values are in %. Col. 6 represents % difference between 1-5 total and bulk value.

Sample No.	#1	#2	#3	#4	#5	%D
360	0	0	11.0	6.0	94.0	-13.0
361	0	0	13.0	28.0	72.0	-0.8
363	0	0	0	21.0	79.0	-6.3
364	0	0	0	24.0	76.0	-9.1
365	0	0	0	4.0	96.0	-4.6
366	0	0	0	13.0	87.0	-9.4
367	0	0	0	14.0	76.0	-0
368	0	0	0	20.0	80.0	-9.5
369	0	0	0	5.0	95.0	-20.0
370	0	0	0	5.0	95.0	5.9
371	0	0	0	13.0	87.0	14.8
372	0	0	0	18.0	82.0	1.0
373	0	0	0	6.0	94.0	-3.2
374	0	0	0	5.0	95.0	-8.3
375	0	0	0	5.0	95.0	-18.4
376	0	0	0	5.0	95.0	-17.4
377	0	0	0	6.0	94.0	-24.0
379	0	0	0	2.0	98.0	-16.0
380	0	0	0	6.0	94.0	-8.5
381	0	0	0	7.0	93.0	14.3
382	0	0	0	8.0	92.0	12.2
383	0	0	0	22.0	78.0	31.6

TABLE 5.13: Distribution of Cu in sequential extracts 1-5. All values are in %. Col. 6 represents % difference between 1-5 total and bulk value.

Sample No.	#1	#2	#3	#4	#5	%D
360	0	0.8	0	42.4	56.8	12.0
361	0	0.3	0.4	35.0	64.2	7.7
363	0	0.8	0	39.1	60.2	7.1
364	0	0.2	0.2	43.1	43.1	7.7
365	0	0	0	45.6	54.4	12.9
366	0	0	0	37.5	62.5	2.7
367	0	0	0	40.1	53.4	3.1
368	0	0	0.7	42.6	42.6	7.2
369	0	0	0	43.3	56.7	7.2
370	0	0	0	27.7	72.3	9.9
371	0	0	0	36.4	63.6	-4.3
372	0	0	0	40.9	59.1	6.9
373	0	0	0	35.0	65.0	23.1
374	0	0	0	29.0	70.1	13.0
375	0	0	0	31.1	68.9	6.3
376	0	0	0	34.5	65.5	4.7
377	0	0	0	29.5	70.4	5.1
379	0	0	1.4	31.3	67.4	13.8
380	0	0	0	68.3	68.3	4.9
381	0	0	0	68.8	60.7	0.4
382	0	0.5	0	38.0	60.8	1.3
383	0	0.3	0.5	46.1	53.2	16.4

TABLE 5.14: Distribution of Fe in sequential extracts 1-5. All values are in %. Col. 6 represents % difference between 1-5 total and bulk sample value.

Sample No.	#1	#2	#3	#4	#5	%D
360	0.1	0.1	0.1	1.0	99.0	8.5
361	0.1	.2	0.1	0.8	99.1	10.1
363	0.1	0.1	0.1	0.7	99.2	6.9
364	0.1	0.1	0.1	.09	99.0	8.7
365	0.1	0.1	0.1	0.6	99.4	-1.4
366	0.1	0.1	0.1	1.3	98.6	1.8
367	0.1	0.1	0.1	0.1	98.6	3.1
368	0.1	0.1	0.1	1.4	98.5	4.8
369	0.1	0.1	0.1	1.0	99.0	5.3
370	0.1	0.1	0.1	1.5	98.4	8.4
371	0.1	0.1	0.1	1.1	98.9	-4.4
372	0.1	0.1	0.1	1.0	98.9	7.5
373	0.1	0.1	0.1	2.2	97.7	4.6
374	0.1	0.1	0.1	2.8	97.2	8.4
375	0.1	0.1	0.1	2.4	97.6	2.6
376	0.1	0.1	0.1	2.2	97.8	5.3
377	0.1	0.1	0.1	1.9	98.0	5.9
379	0.1	0.1	0.1	0.8	99.2	2.5
380	0.1	0.1	0.1	1.2	98.8	2.4
381	0.1	0.1	0.1	1.5	98.5	5.2
382	0.1	0.1	0.1	1.5	98.5	11.7
383	0.1	0.1	0.1	1.4	98.5	30.5

TABLE 5.15: Distribution of Mn in sequential extracts 1-5. All values are in %. Col. 6 represents % difference between 1-5 total and bulk sample value.

Sample No.	#1	#2	#3	#4	#5	%D
360	0	0	6.5	14.5	79.0	9.4
361	4.3	0.2	5.9	32.5	57.3	1.9
363	3.6	0.01	8.5	27.5	60.4	3.5
364	14.2	0.2	6.8	28.7	50.1	1.01
365	0.2	0	6.2	10.1	83.5	3.0
366	1.6	0	7.2	22.5	68.7	3.7
367	1.4	0	3.6	35.7	69.3	3.0
368	3.4	0.03	5.0	31.5	60.1	3.8
369	0.2	0	9.3	15.6	76.0	7.3
370	3.0	0	10.6	30.2	56.2	2.4
371	1.6	0.02	6.1	25.1	67.2	4.1
372	2.8	0.04	6.9	29.6	60.7	3.1
373	0.3	0	12.9	28.1	58.7	3.5
374	0.6	0	17.7	31.1	50.6	2.7
375	0	0.01	19.5	28.3	52.2	3.8
376	0.5	0	12.1	25.5	62.0	-2.3
377	1.2	0	9.8	26.0	63.0	-5.7
379	0	0	6.5	12.4	81.1	3.0
380	0.05	0.02	7.4	33.5	59.0	21.0
381	0.2	0	7.6	27.1	65.2	14.3
382	0.04	0	9.1	35.1	35.1	18.2
383	0.4	0	6.8	46.5	46.5	16.5

TABLE 5.16: Distribution of Ni in sequential extracts 1-5. All values are in %. Col. 6 represents % difference between 1-5 total and bulk sample value.

Sample No.	#1	#2	#3	#4	#5	%D
360	0	0	0	6.0	94.0	16.4
361	1.5	0	0	9.0	89.5	7.6
363	0	0	0	6.3	93.7	15.3
364	1.7	0	0	10.7	87.7	0
365	0	0	0	5.7	94.3	18.5
366	3.0	0	0	3.5	93.5	6.9
367	2.5	0	0	4.6	92.8	5.2
368	0	0	0	6.8	93.2	1.7
369	0	0	0	12.3	87.7	36.7
370	0	0	0	4.8	95.2	2.0
371	0	0	0	5.9	94.1	6.3
372	2.6	0	0	7.8	89.6	16.3
373	5.1	0	0	12.4	82.5	21.3
374	0	0	0	4.8	95.2	5.0
375	0	0	0	7.6	92.4	19.0
376	0	0	0	7.5	92.5	7.5
377	0	0	0	9.1	90.9	20.0
379	0	0	0	6.3	937.0	-6.7
380	0	0	0	0	100.0	17.6
381	0	0	0	5.1	94.9	-16.8
382	0	0	0	5.7	94.3	-1.9
383	0	0	0	21.0	79.0	30.0

TABLE 5.17: Distribution of Pb in sequential extracts 1-5. All values are in %. Col. 6 represents % difference between 1-5 total and bulk sample value.

Sample No.	#1	#2	#3	#4	#5	%D
360	0	0	0	27.0	73.0	27.5
361	0	0	0	21.0	79.0	7.5
363	0	0	0	19.0	81.0	3.7
364	0	0	0	20.0	80.0	11.4
365	0	0	0	29.0	71.0	11.4
366	0	0	0	30.0	70.0	11.4
367	0	0	0	31.0	69.0	2.1
368	0	0	0	23.0	77.0	18.2
369	0	0	0	29.0	71.0	8.0
370	0	0	0	25.0	75.0	6.0
371	0	0	0	21.0	79.0	-3.8
372	0	0	0	27.0	73.0	1.8
373	0	0	0	25.0	75.0	30.0
374	0	0	0	15.0	85.0	0
375	0	0	0	21.0	79.0	23.5
376	0	0	0	12.0	88.0	11.8
377	0	0	0	22.0	78.0	11.8
379	0	0	0	23.0	77.0	39.0
380	0	0	0	19.0	81.0	12.6
381	0	0	0	31.0	69.0	17.7
382	0	0	0	26.0	74.0	8.8
383	0	0	0	25.0	75.0	21.0

TABLE 5.18: Distribution of Zn in sequential extracts 1-5. All values are in %. Col. 6 represents % difference between 1-5 total and bulk sample value.

Sample No.	#1	#2	#3	#4	#5	%D
360	0.9	0.25	1.1	12.4	85.4	-1.3
361	0.4	0.2	0.3	30.3	68.8	3.9
363	0.4	0.1	0.2	21.7	77.6	4.7
364	0.3	0.1	0.3	26.3	73.1	9.9
365	0.6	0.1	1.0	11.6	86.6	-8.6
366	0.5	0.2	0.6	21.2	77 5	-11.4
367	0.6	0.1	0.3	23.3	75.7	0.9
368	0.5	0.1	0.2	26.8	72.3	-9.2
369	0.9	0.1	1.1	14.6	83.3	-1.4
370	0.5	0.1	0.6	21.6	77.2	2.2
371	0.6	0.1	0.4	21.3	77.7	-5.1
372	0.6	0.1	0.3	24.9	74.1	2.7
373	2.0	0.2	1.2	18.0	78.6	3.1
374	0.8	0.2	1.0	19.5	78.6	-10.5
375	0.9	0.1	1.1	22.3	75.7	5.1
376	0.9	0.1	0.6	13.3	85.1	-15.6
377	0.9	0.1	0.6	13.4	85.1	-6.1
379	0.5	-.1	0.6	8.7	90.1	-26.8
380	0.5	0.1	0.2	21.3	77.8	2.3
381	0.7	0.0	0.2	20.1	78.9	9.0
382	0.6	0.1	0.2	23.1	76.1	-15.7
383	0.5	0.0	0.1	30.0	69.4	17.1

TABLE 5.19: Samples demonstrating enhanced levels of metal in Fractions 1 and 3

Sample Location	Cd(1)	Co(1)	Ni(1)	Zn(1)	Mn(1)*	Mn(3)*
363	+					
364		+			+	
366			+			
367			+			
370						+
373				+		+
374			+			+
375	+					+
376	+					+

* Values above 5%

TABLE 5.20: Study area contaminated stations based on MOE Guidelines for open water dredged sediment disposal (MOE, 1976)

Station No.	Ni	Pb	Cu	Zn	Cr	Fe	Mn*	Cd
360					0	+		0
361	0	0	0	0	+	+	H	0
363	0	0	0	0	+	+	H	0
364	0	0	+	+	+	+	H	+
365					0	+	H	
366				0	0	0	H	
367	0	0	0	0	+	0	H	0
368		0	0	0	+	0	H	0
369					0	0	H	
370				0	0	0	H	
371				0	0	0	H	
372	0	0	0	0	+	+	H	0
373					0	0	H	
374					0	0	H	
375					0	0	H	
376					0	0	H	
377					0	0	H	0
378	0	0	0	0	+	+	H	0
379					+	+	H	
380			0	0	0	+	H	
381				0	0	+	H	
382	0	0	0	0	0	+	H	
383	0	0	+	+	+	+	H	0
Guideline (ppm)	25	50	25	100	25	10,000 1.0%	*	1.0

0 Contaminated, Above MOE Guideline.
+ Highly contaminated (3X MOE Guideline).
- Clean (Below MOE Guideline)
* MOE Guideline not established; Based on EPA (1979) classification.
* L Light
* M Moderate
* H Heavy

TABLE 5.21: Depth, substrate type and diversity index in bottom sample.

Sample Location No.	Depth (cm)	Substrate Type	Diversity Index
360	400	Bedrock/Sand	2.14
360A	400	Bedrock/Sand	1.51
361	900	Sand	3.11
362	1500	Gravel	2.46
362A	1500	Gravel	3.00
363	1900	Silt/Clay	2.43
363A	1900	Silt/Clay	2.20
364	3100	Clay	1.92
364A	3100	Clay	2.36
365	450	Sand	2.28
365A	450	Sand	1.72
366	900	Silt/Clay	3.22
366A	900	Silt/Clay	3.17
367	1450	Silt/Clay	3.00
367A	1450	Silt/Clay	2.21
368	2000	Silt/Clay	2.74
368A	2000	Silt/Clay	3.06
369	400	Sand	1.22
370	1050	Sand	2.91
370A	1050	Sand	2.42
371	1500	Silt/Clay	1.36
371A	1500	Silt/Clay	2.57
372	2000	Sand	2.47
372A	2000	Sand	2.06
373	400	Sand	2.11
374	550	Sand	1.99
374A	550	Sand	1.91
375	1000	Silt/Sand	2.14
375A	1000	Silt/Sand	2.17
376	1500	Silt/Sand	2.16
376A	1500	Silt/Sand	2.32
377	2000	Silt/Sand	2.44
377A	2000	Silt/Sand	2.04
378A	1000	Silt/Sand	2.14
379	500	Sand	2.40
379A	500	Sand	1.18
380	1000	Sand	3.05
380A	1000	Sand	2.75
381	1500	Silt/Sand	2.10
382	1000	Silt/Sand	2.05
382A	1000	Silt/Sand	1.92
383	3000	Silt/Sand	1.21
383A	3000	Silt/Sand	1.40
386			1.35

364 - Initial Sample

364A - Duplicate Sample

TABLE 5.22: Analysis of Variance Results for Increase or Decrease of Variables in Deep and Shallow Water Sites

Variable demonstrating F Ratio >4.59 at 95% confidence level	Site Comparison of <6 m versus> 11 m depth. Increase (+) or Decrease (-) of variable in deep water sites	Site comparison of <6m. versus depths between 6 and 11m. Increase (+) or Decrease (-) of variable in shallow water sites
Cadmium fraction 6	-	
Copper fraction 5	+	-
Copper fraction 6	+	-
Iron fraction 5	-	+
Iron fraction 6	-	+
Manganese fraction 5	-	+
Manganese fraction 6	-	
Nickel fraction 5	+	+
Nickel fraction 6	+	
Lead fraction 5	+	-
Lead fraction 6	+	-
Zinc fraction 5	+	-
Zinc fraction 6	+	-
Diversity Index	+	-
Pisidium casertanum	+	
Sphaerium nitidum	+	
Micropsectra sp.	+	
Chironomus (chironomus) thummi (riparius)	-	
Pontoporeia sp.	+	-
Lumbricus Variegatus	+	-

TABLE 5.23 BENTHIC MACROINVERTEBRATES IDENTIFIED WITHIN THE STUDY AREA

TAXA	SPECIES	No. Stations Identified
Oligochaeta-Tubificide	Immature capilliform sp.	24
	Immature non-capilliform sp.	41
	Potamothrix vejdovskyi	16
	Potamothrix hammoniensis	3
	Potamothrix moldavensis	15
	Polescolex ferox	11
	Tubifex tubifex	6
	Aulodrilus americanus	1
	Limnodrilus hoffmeisteri	18
	Limnodrilus maumeensis	1
	Limnodrilus spp.	3
Bivalvia Sphaeriidae	Sphaerium nitidum	20
	Pisidium casertanum	37
	Pisidium henslowanum	25
	Pisidium lilljeborgi	7
	Pisidium canventus	5
	Pisidium compressum	2
	Pisidium idahoense	6
	Pisidium nitidum	2
	Pisidium variable	2
	Pisidium ferrugineum	2
	Pisidium substruncatum	2
Amphipoda-Pontogeniidae	Pontoporeia sp.	36
Lumbriculidae	Lumbricus variegatus	34
Oligochaeta-Naididae	Nais sp.	2
Insecta-Chironomidae	Paracladopelma sp.	2
	Heterotrissocladium sp.	14
	Psectrocladius sp.	14
	Pagastia sp.	11
	Dicrotendipes sp.	3
	Chironomus (Chironomus) thummi (riparius)	11
	Cryptochironomus sp.	6
	Polypedilum sp.	4
	Micropsectra sp.	21
	Monodiamesa sp.	2
	Procladium sp.	14
Asellidae	Asellus recovitzai recovitzai	9
Gastropoda-Valvatidae	Valvata tricarinata	4
	Valvata sincera	8
Gastropoda-Planorbidae	Gyraulus hirsutus	1
Amphipoda-Gammaridae	Gammarus fasciatus	3
Hirudinea-Glossiphonidae	Glossiphonidae sp.	1
	Helobdella stagnalis	

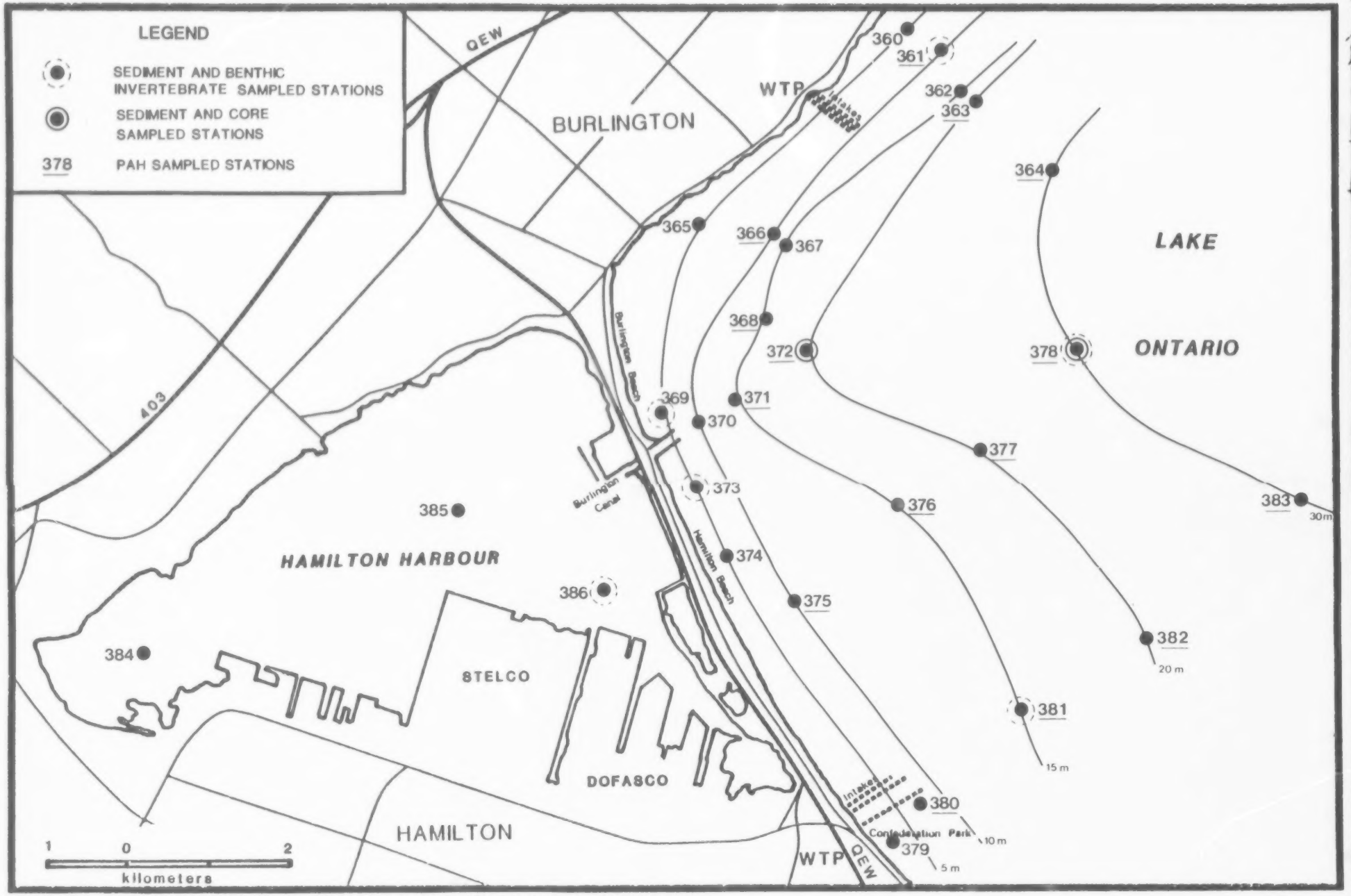

FIG.5.1 : STATION LOCATIONS AND DEPTH CONTOURS OF THE STUDY AREA

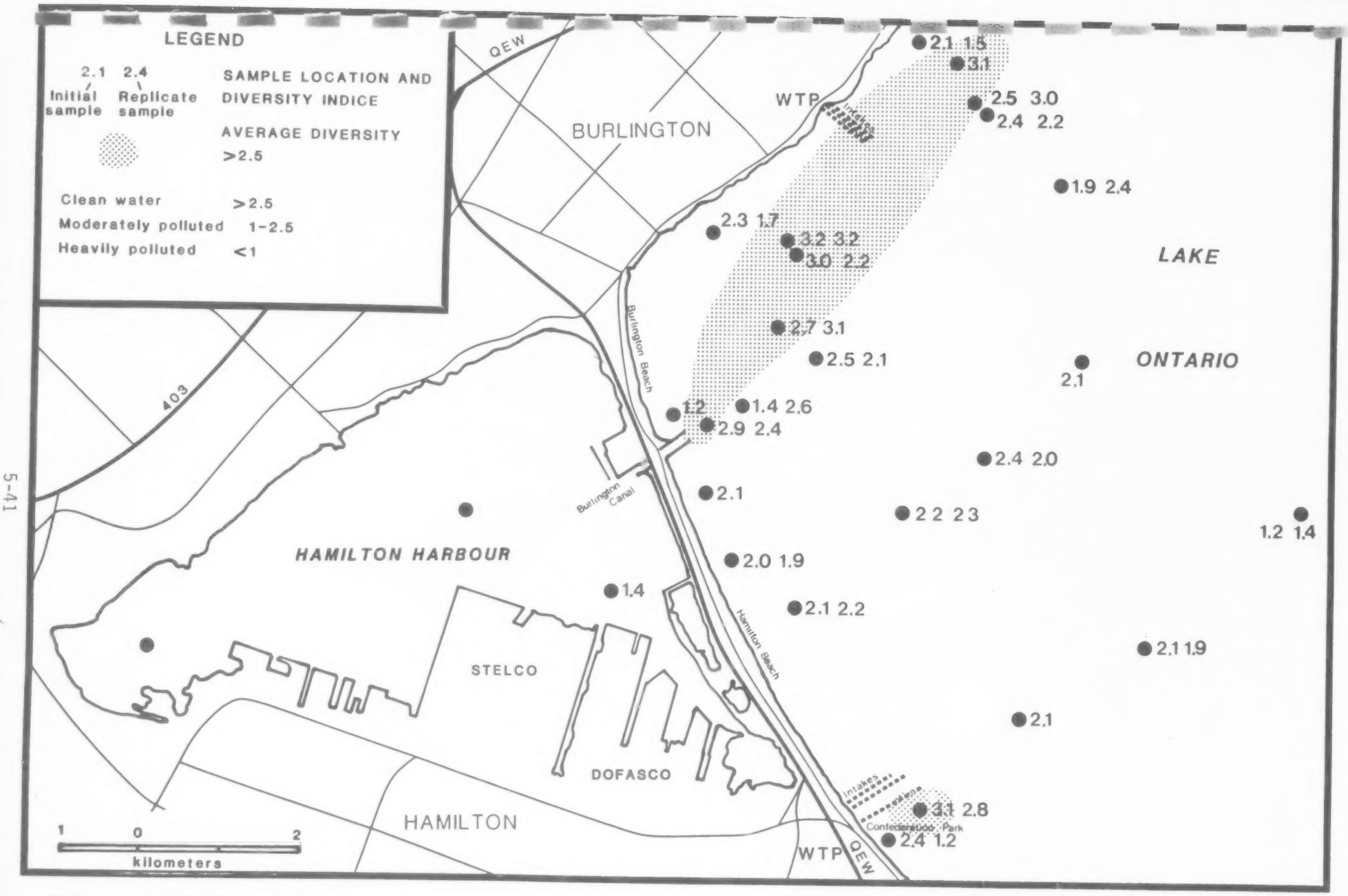

FIG.5.2 : DIVERSITY INDEX

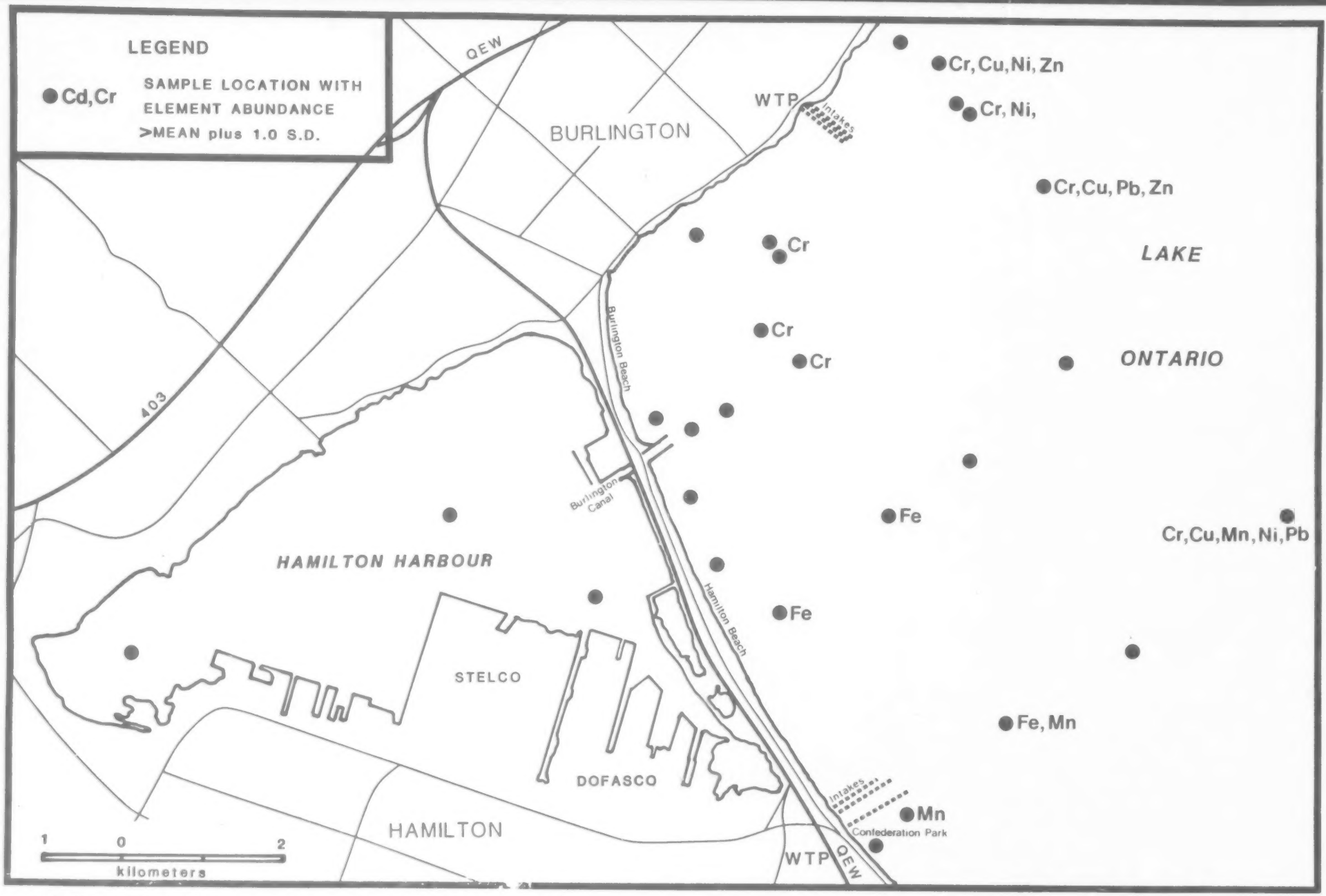

FIG. 5.3 : FRACTION 4 METAL RESULTS

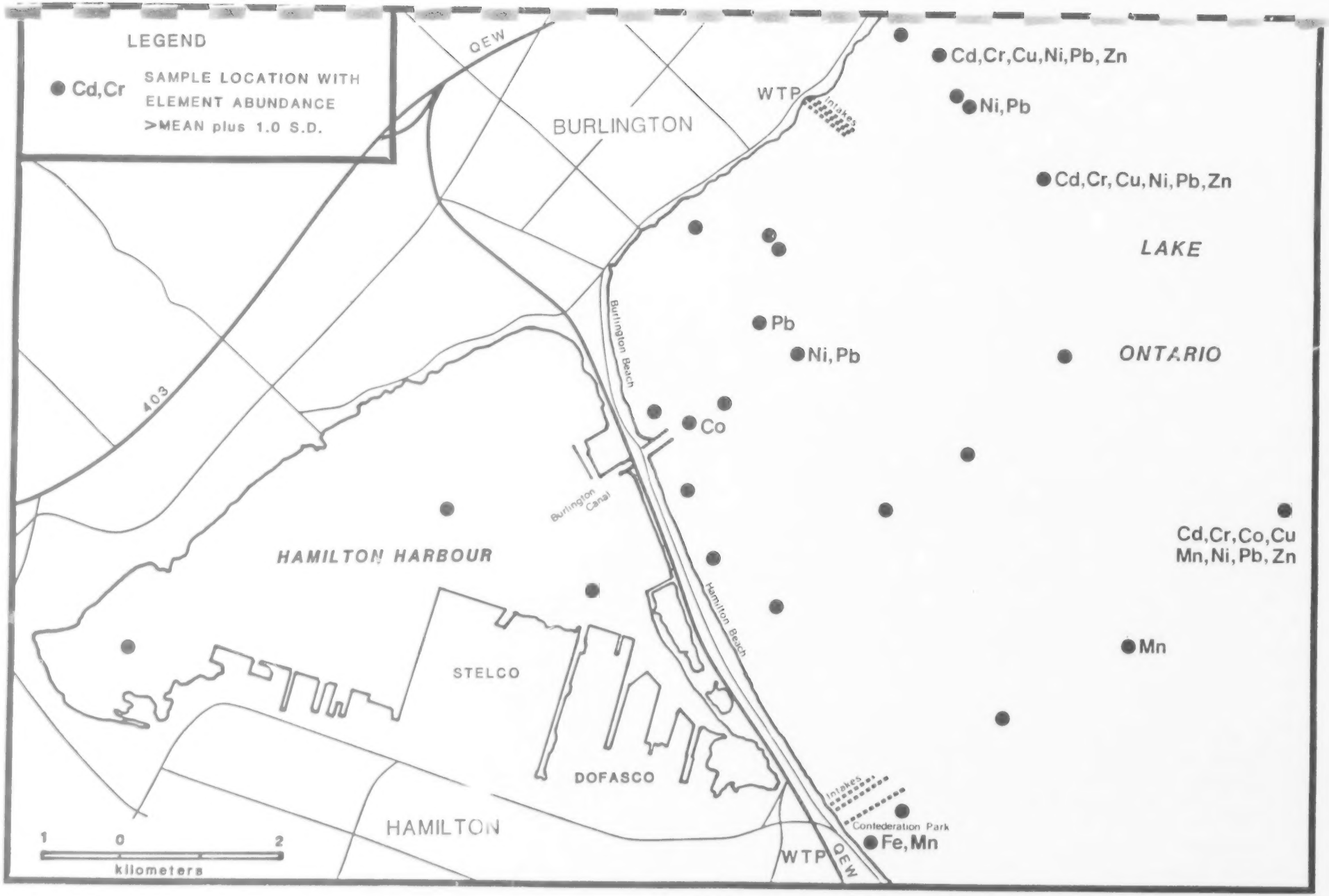

FIG.5.4 : FRACTION 5 METAL RESULTS

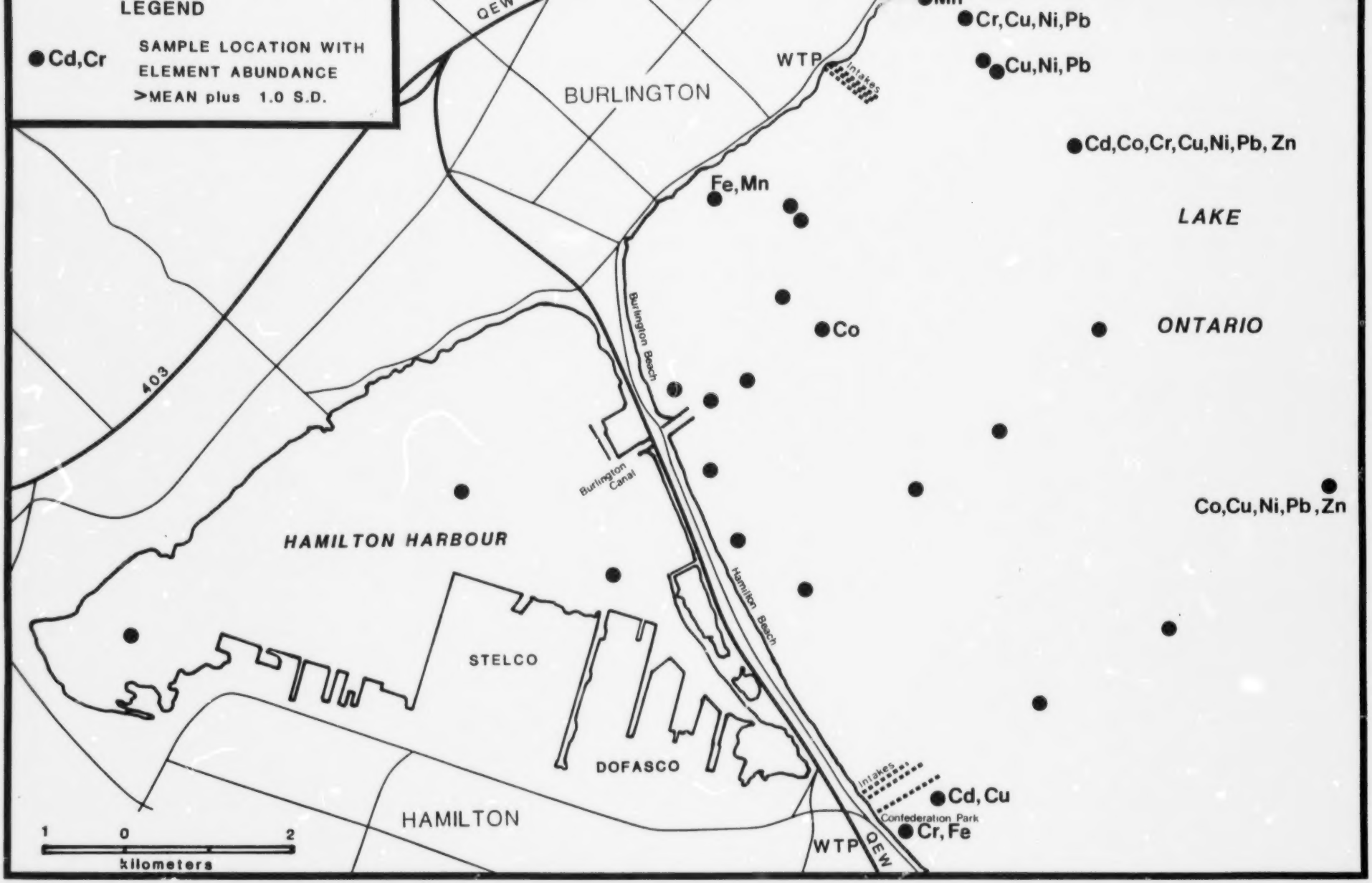

FIG.5.5: FRACTION 6 METAL RESULTS

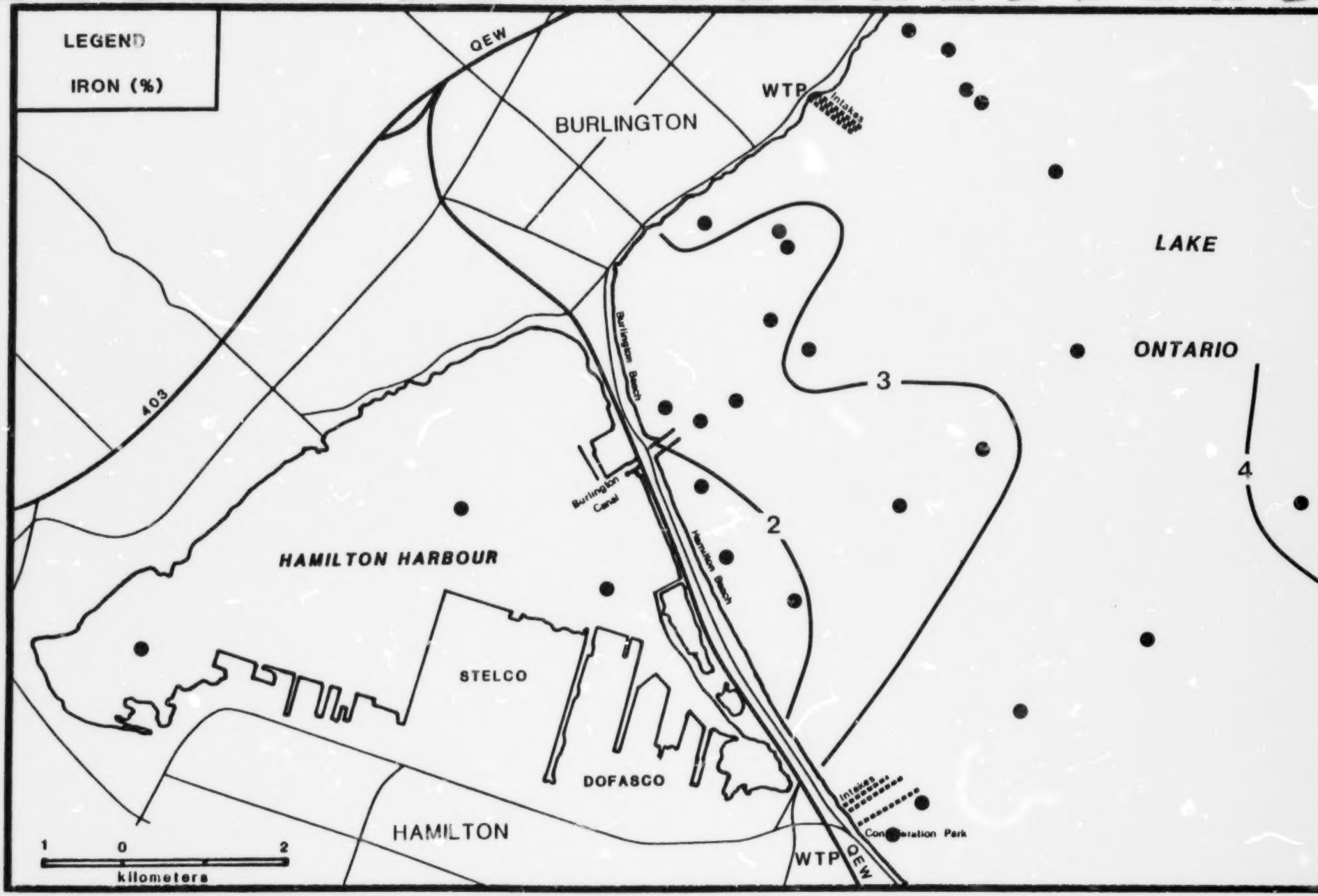

FIG.5.6 : TOTAL IRON CONCENTRATIONS IN SEDIMENT OF WESTERN LAKE ONTARIO, AUGUST, 1983

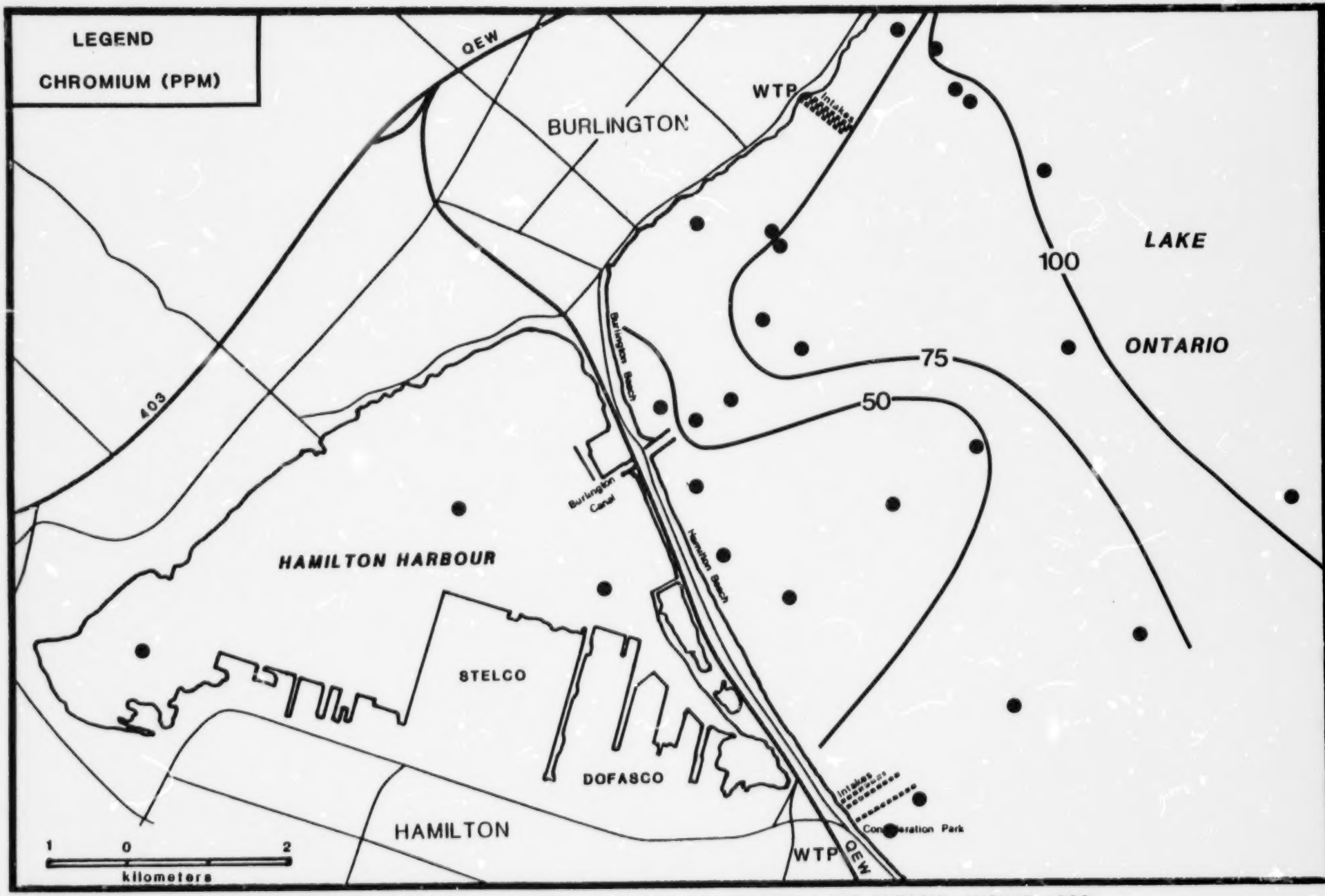

FIG.5.7 : TOTAL CHROMIUM CONCENTRATIONS IN SEDIMENT SAMPLES OF WESTERN LAKE ONTARIO, AUGUST, 1983

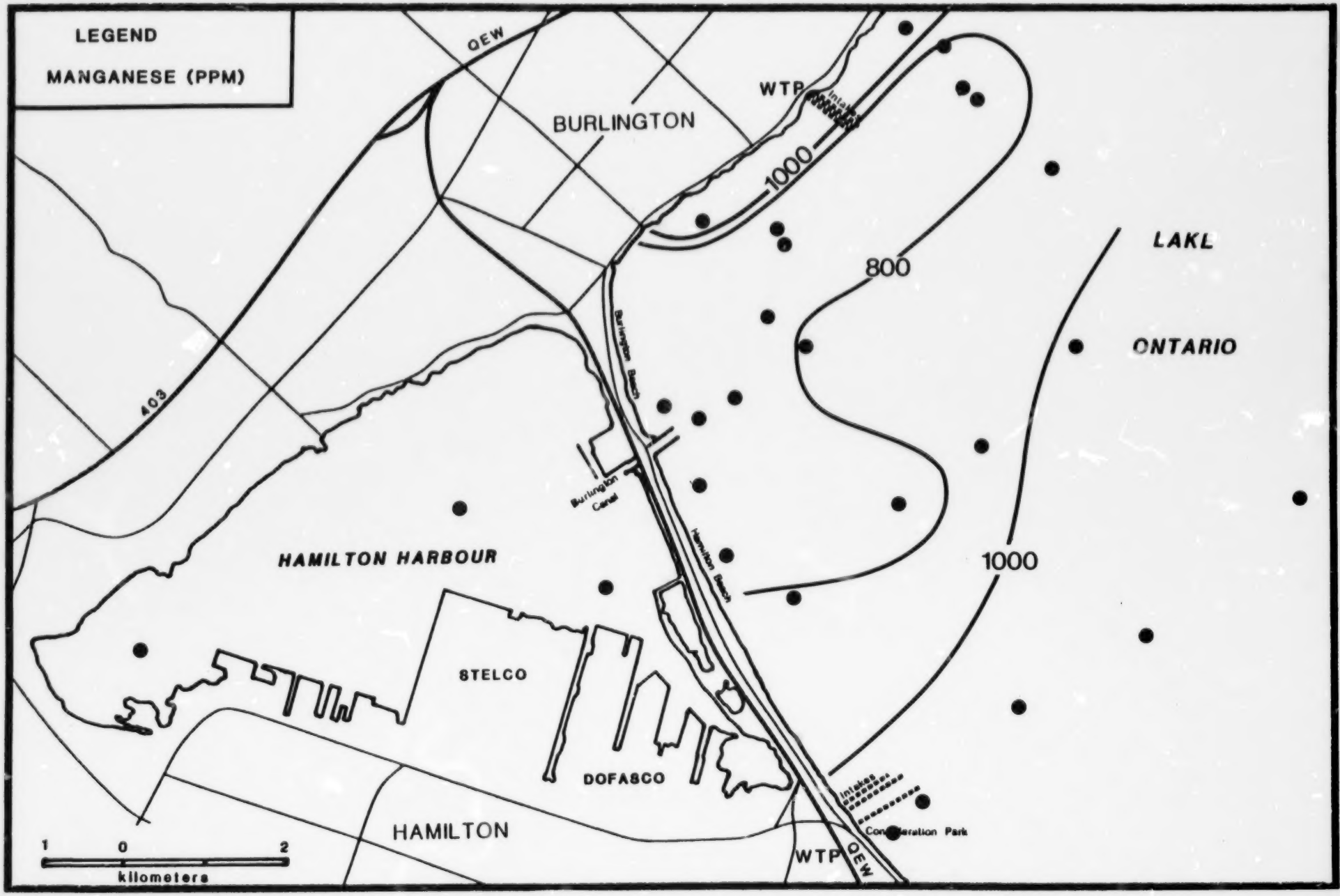

FIG.5.8 : TOTAL MANGANESE CONCENTRATIONS IN SEDIMENT SAMPLES OF WESTERN LAKE ONTARIO , AUGUST, 1983

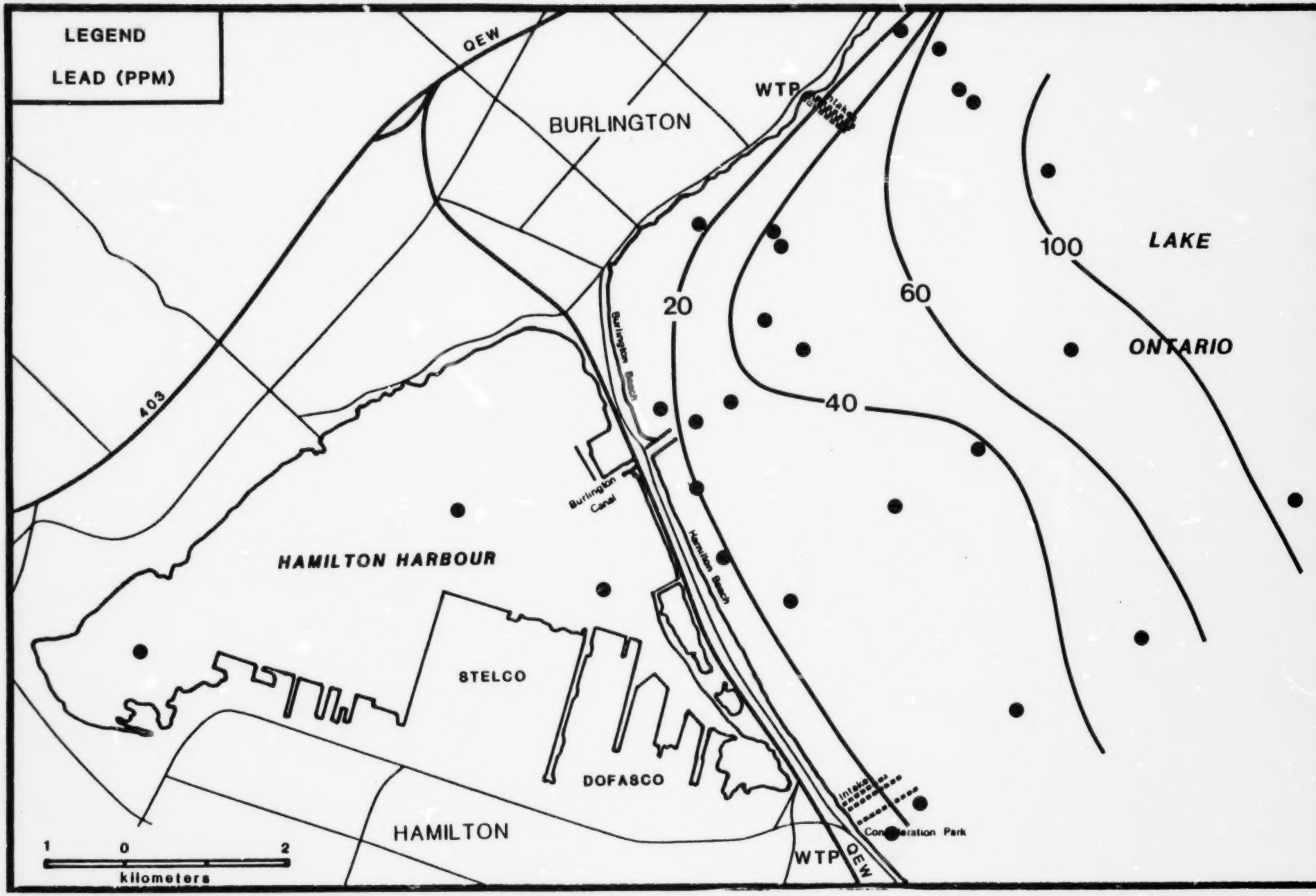

FIG.5.9 : TOTAL LEAD CONCENTRATIONS IN SEDIMENT SAMPLES OF WESTERN LAKE ONTARIO, AUGUST, 1983

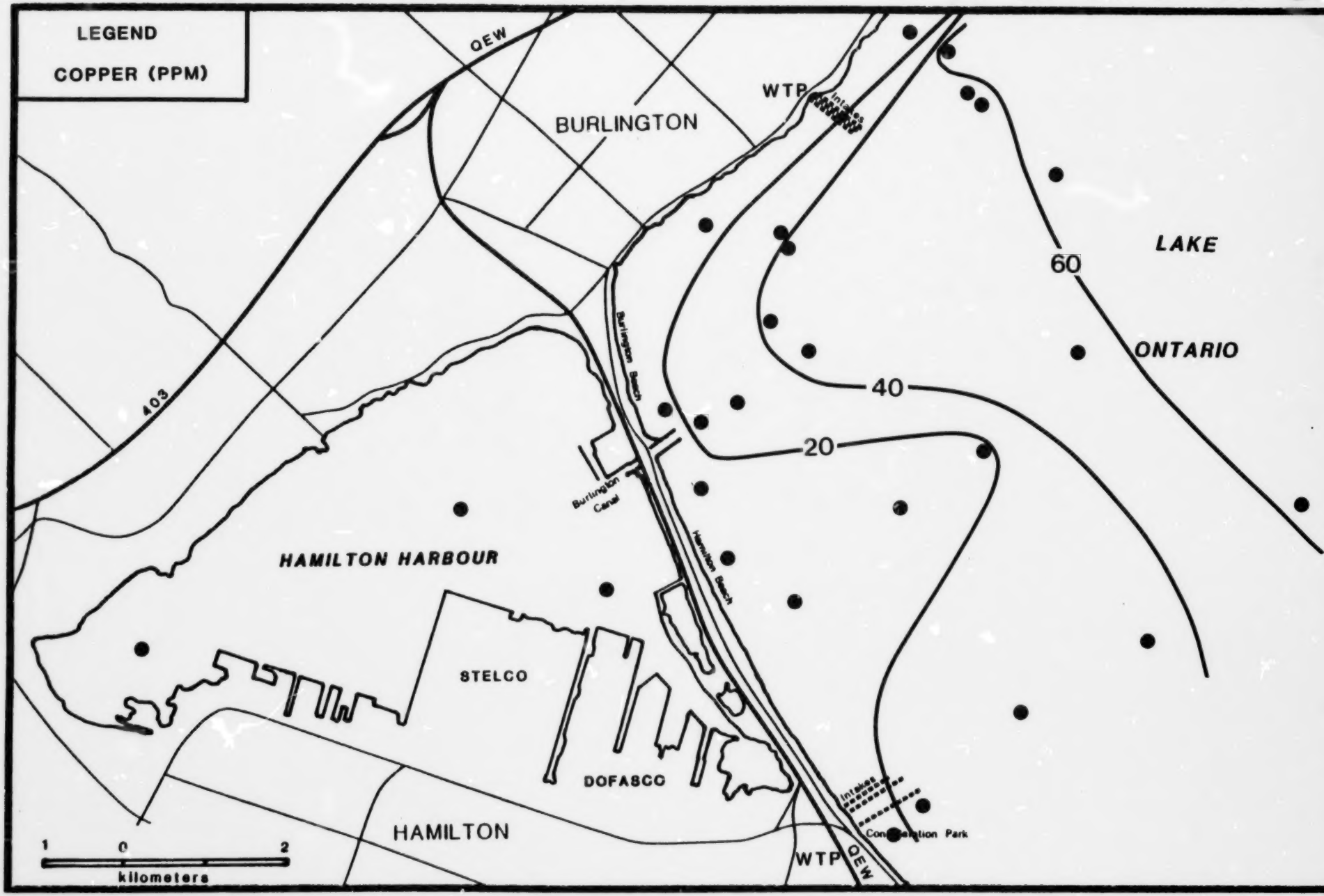

FIG.5.10 : TOTAL COPPER CONCENTRATIONS IN SEDIMENT SAMPLES OF WESTERN LAKE ONTARIO, AUGUST,1983

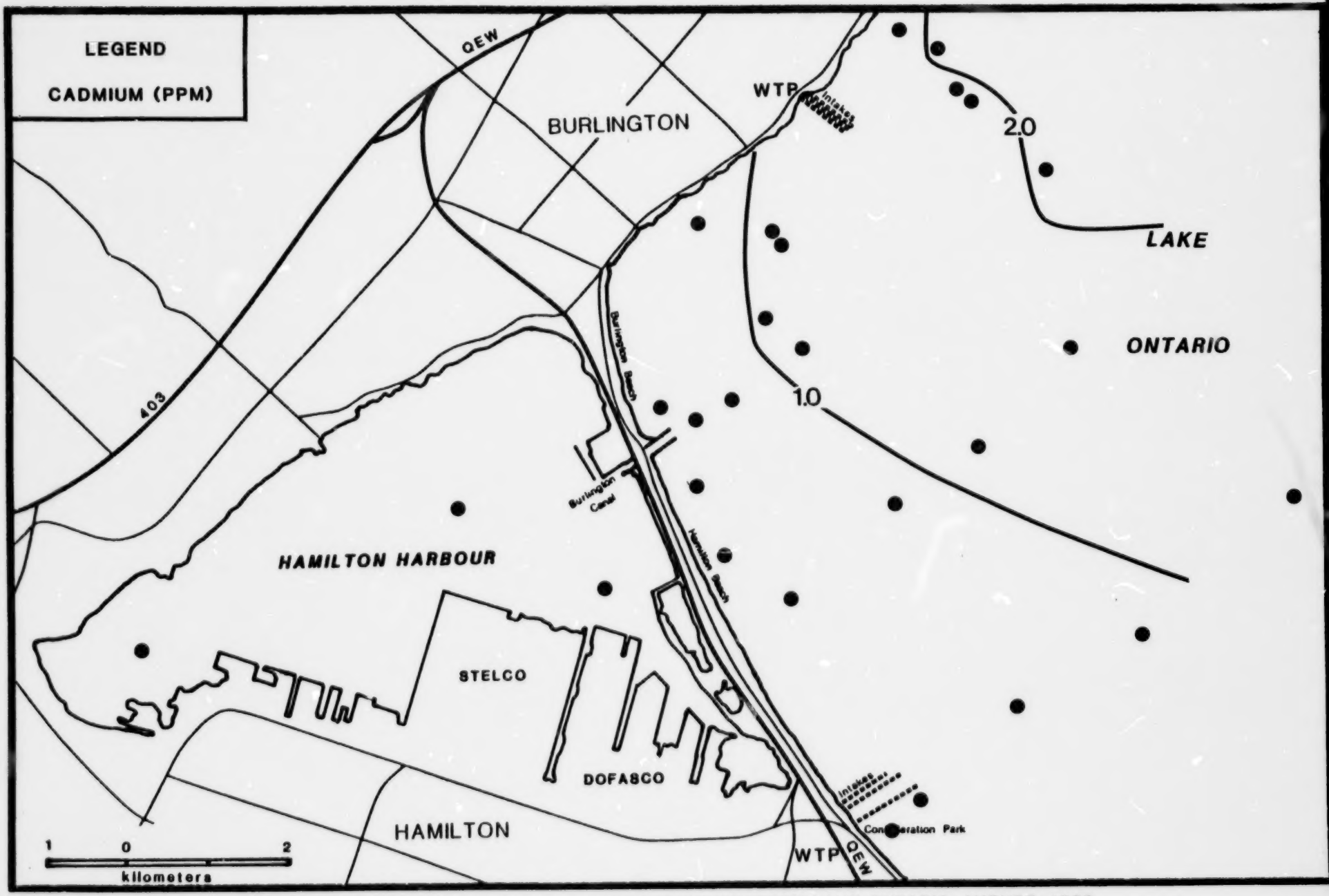

FIG.5.11 : TOTAL CADMIUM CONCENTRATIONS IN SEDIMENT SAMPLES OF WESTERN LAKE ONTARIO, AUGUST, 1983

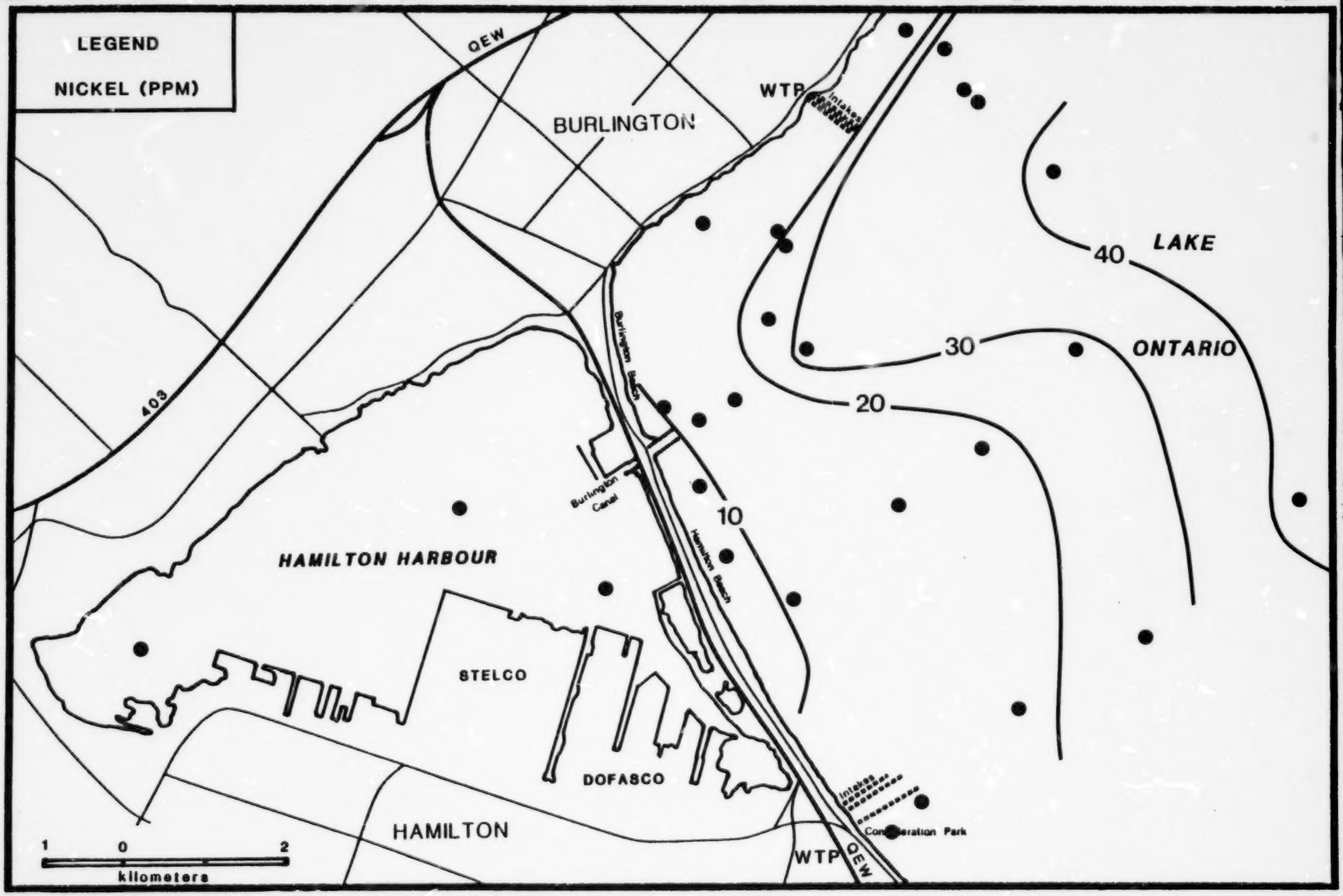

FIG. 5. 12 : TOTAL NICKEL CONCENTRATIONS IN SEDIMENT SAMPLES OF WESTERN LAKE ONTARIO, AUGUST, 1983

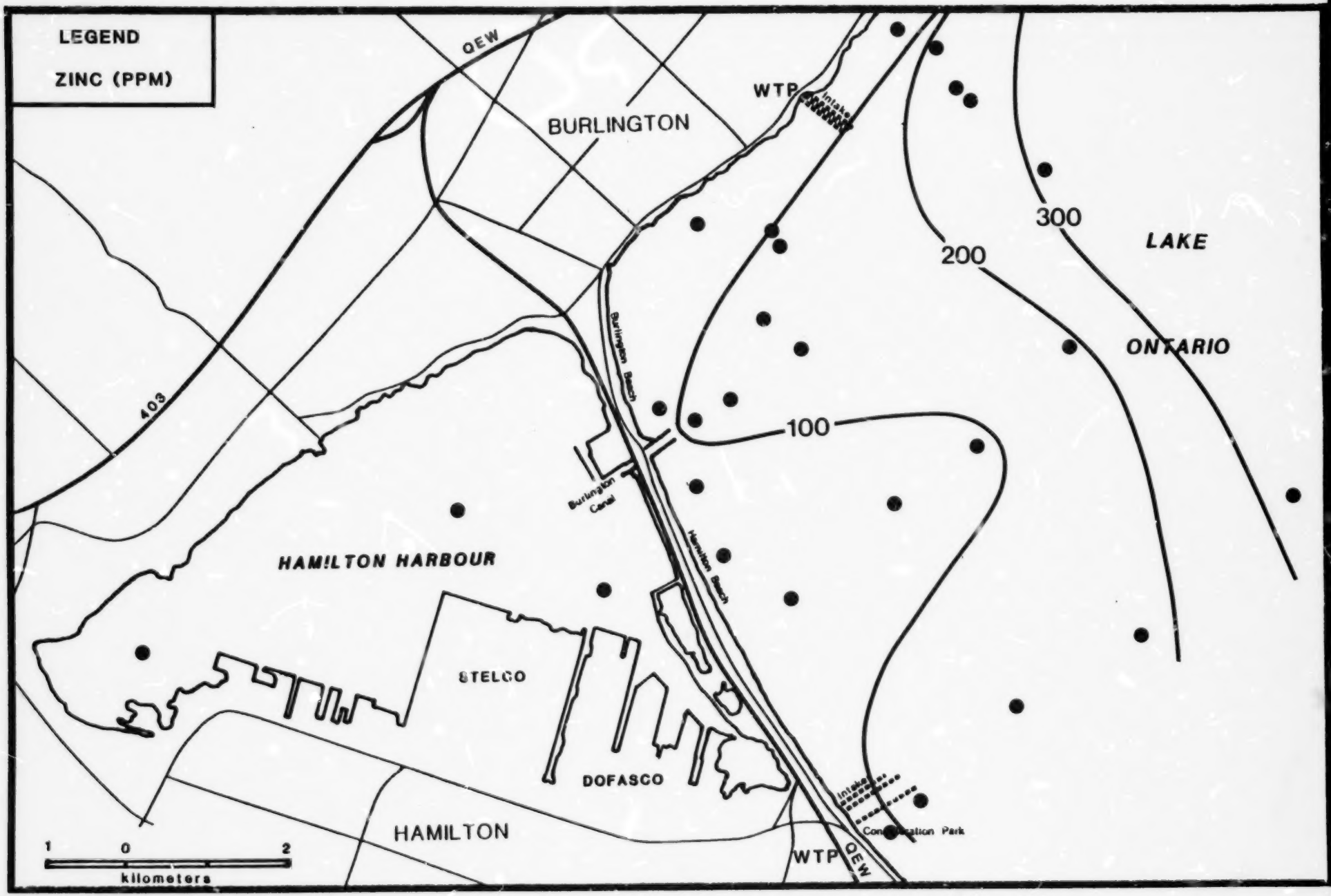

FIG.5.13 : TOTAL ZINC CONCENTRATIONS IN SEDIMENT SAMPLES OF WESTERN LAKE ONTARIO, AUGUST, 1983

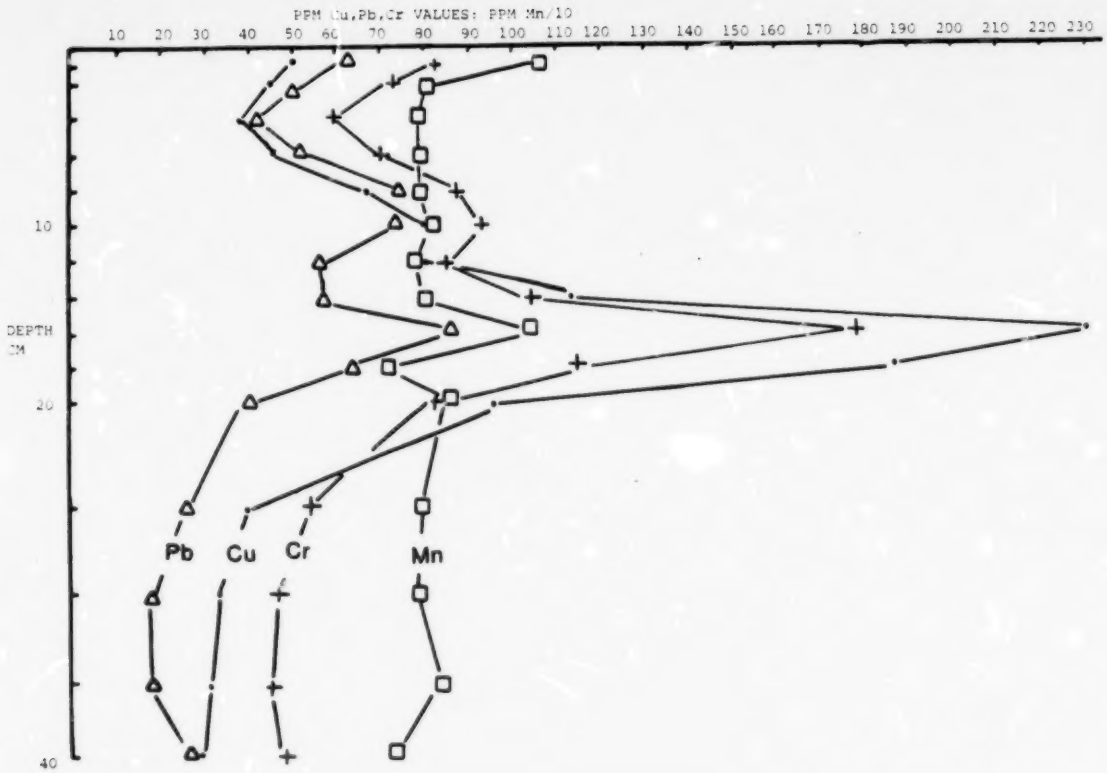

FIG.5.14: **DISTRIBUTION OF TRACE ELEMENTS IN VERTICLE SEDIMENT CORE SAMPLES AT SITE 372**

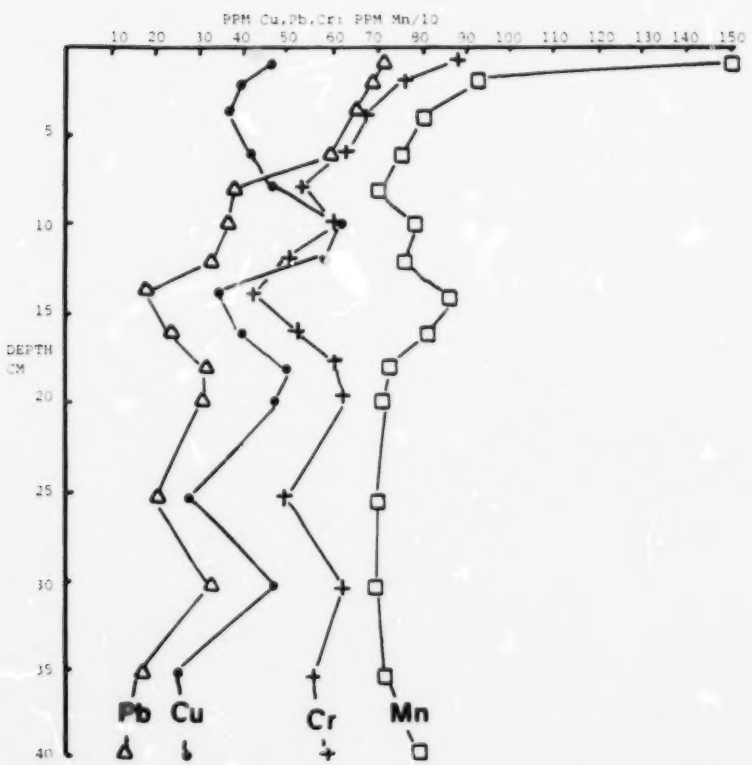

FIG.5.15: **DISTRIBUTION OF TRACE ELEMENTS IN VERTICLE SEDIMENT CORE SAMPLES AT SITE 378**

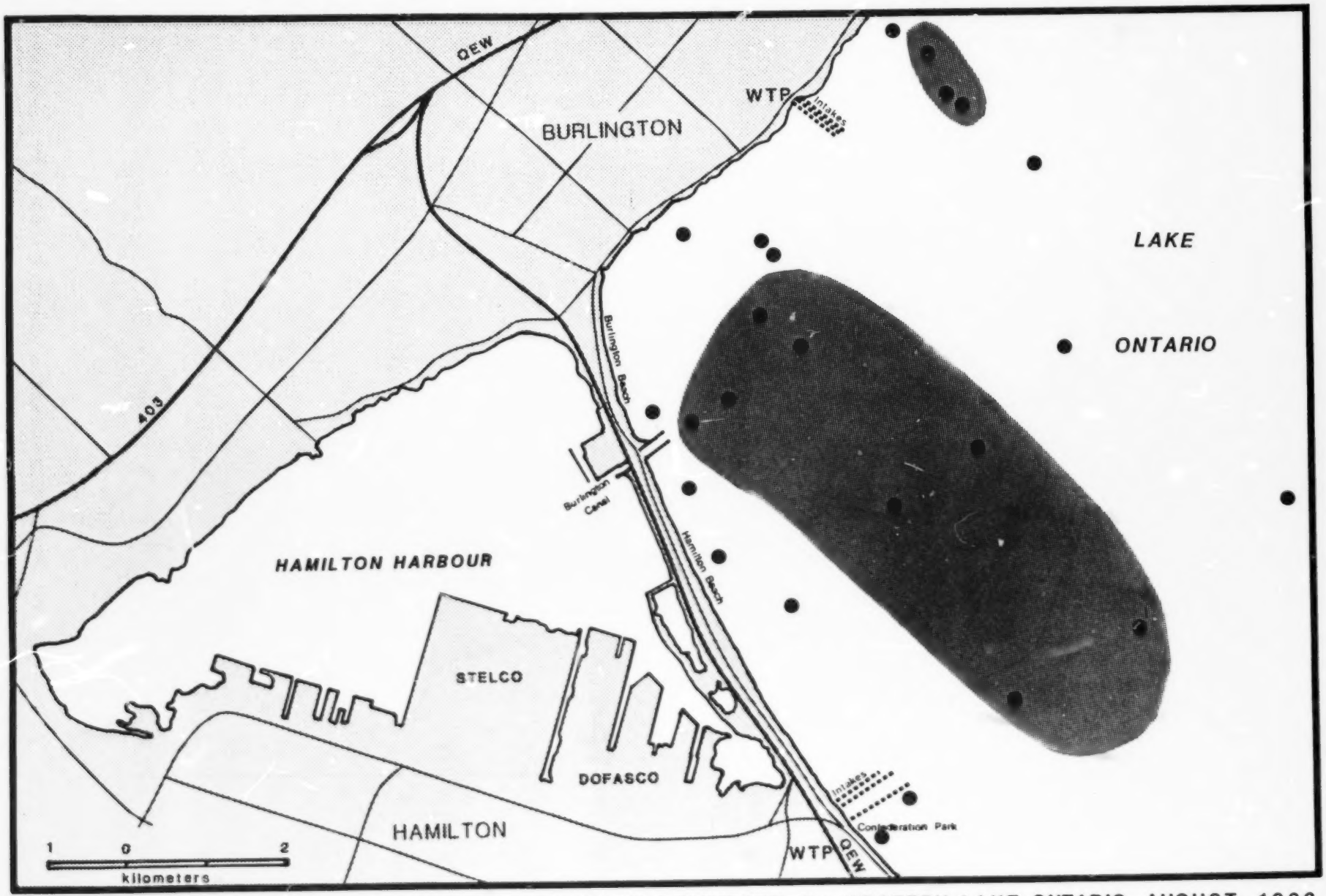

FIGURE 5.16 : OCCURENCE OF SPHAERIUM NITIDUM IN SEDIMENTS OF WESTERN LAKE ONTARIO, AUGUST 1983

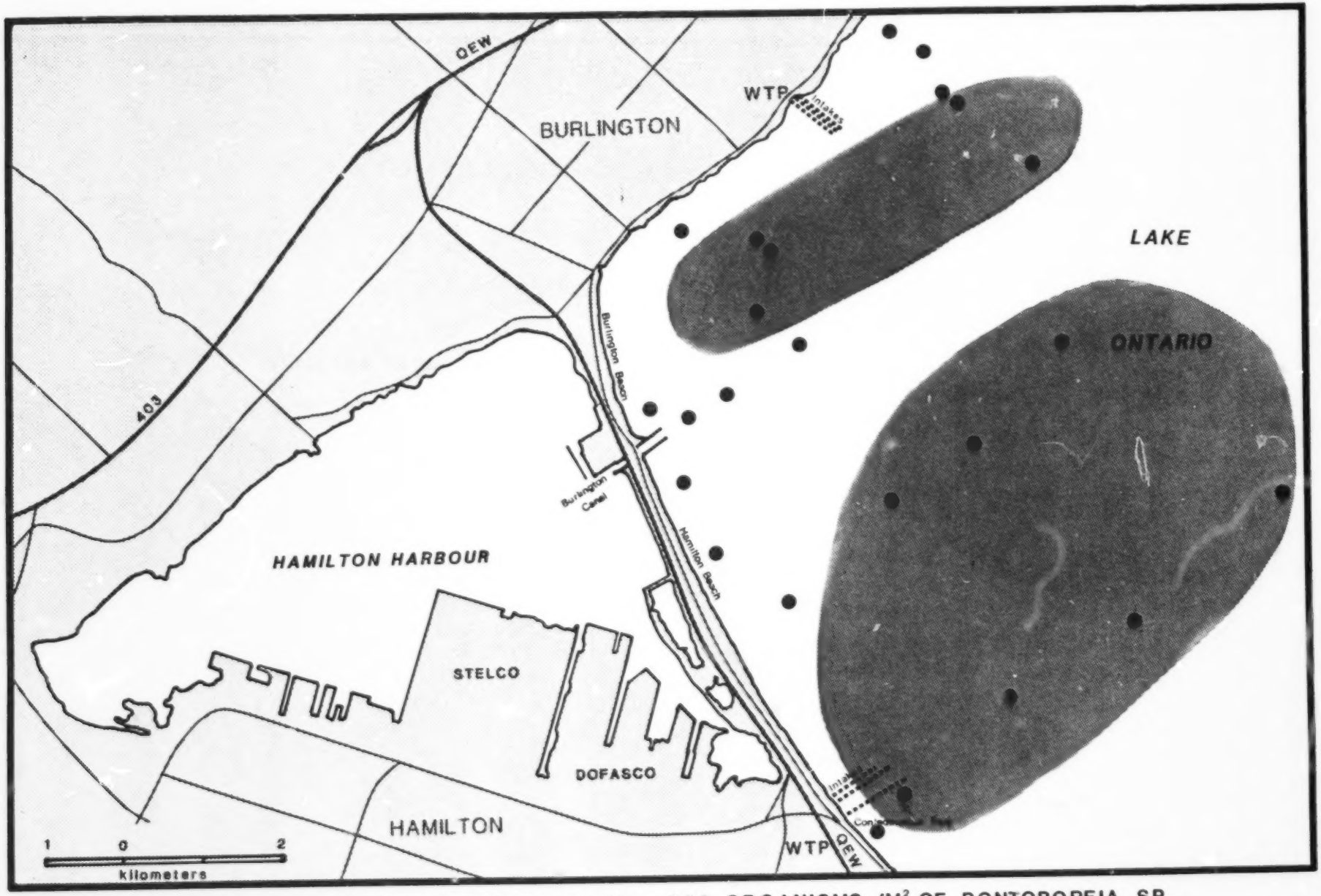

FIGURE 5.17 : AREA OF WESTERN LAKE ONTARIO WITH > 500 ORGANISMS /M^2 OF PONTOPOREIA SP., AUGUST 1983

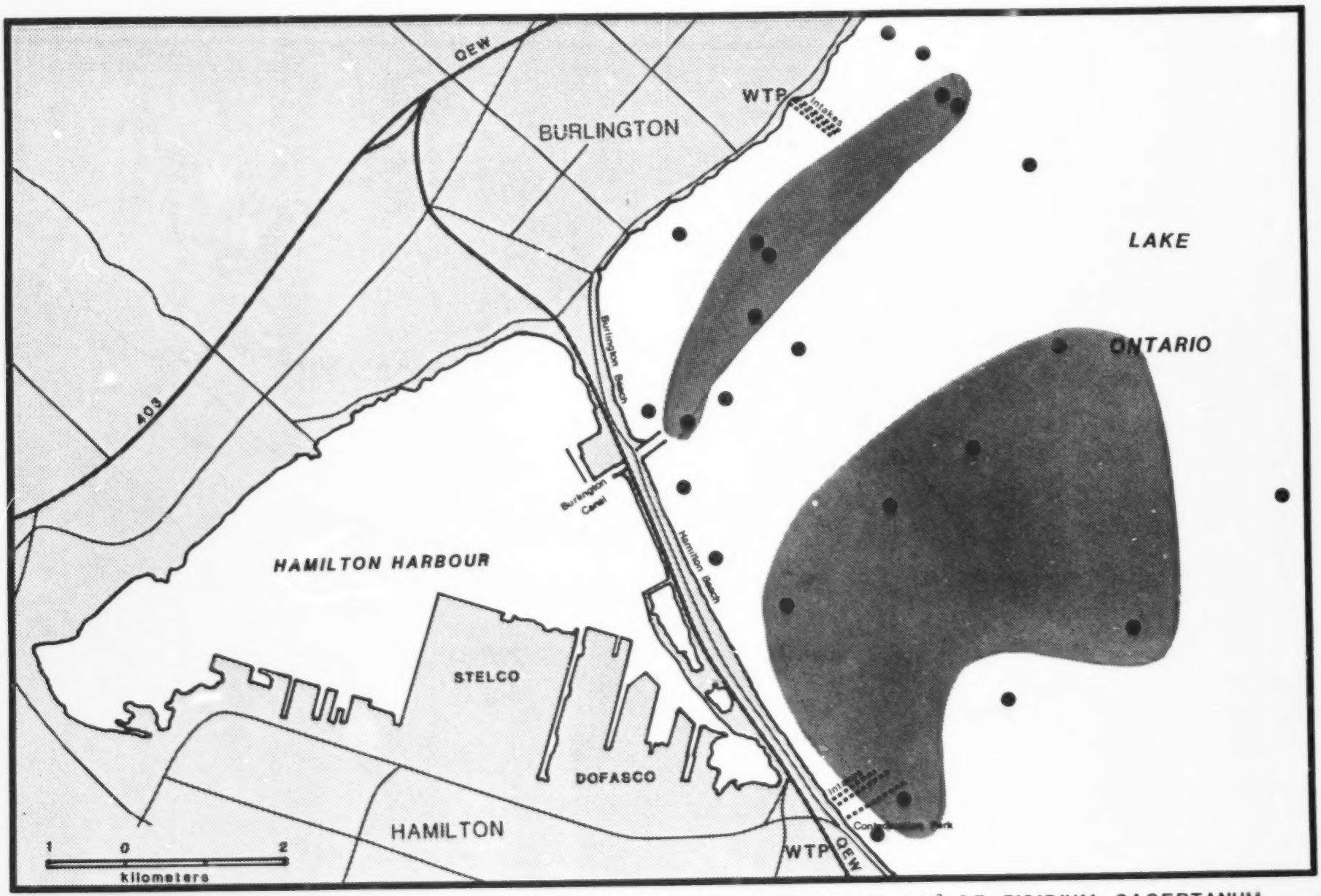

FIGURE 5.18 : AREA OF WESTERN LAKE ONTARIO WITH > 500 ORGANISMS / M^2 OF PISIDIUM CASERTANUM, AUGUST 1983

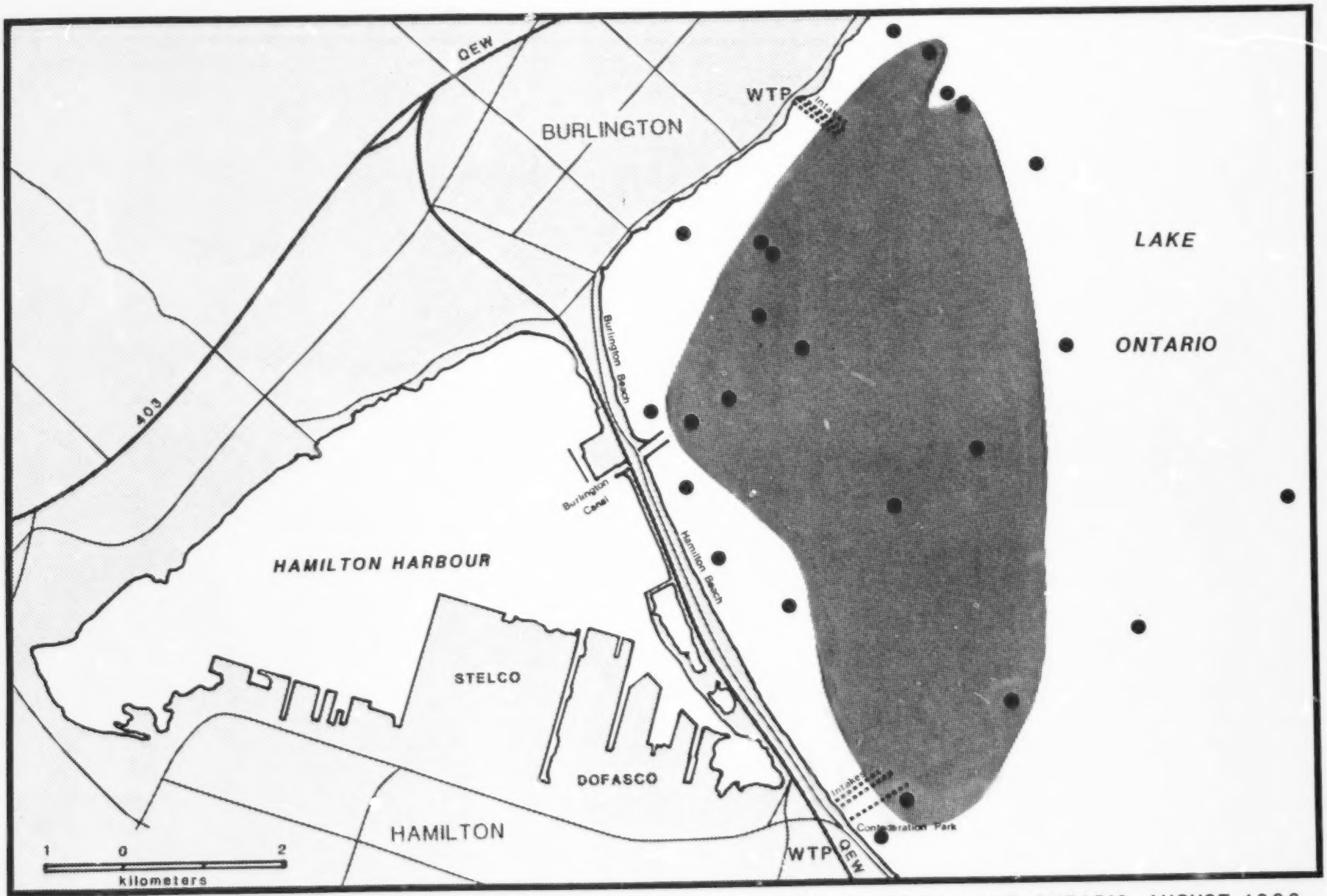

FIGURE 5.19 : OCCURENCE OF MICROSPECTRA SP. IN SEDIMENTS OF WESTERN LAKE ONTARIO, AUGUST 1983

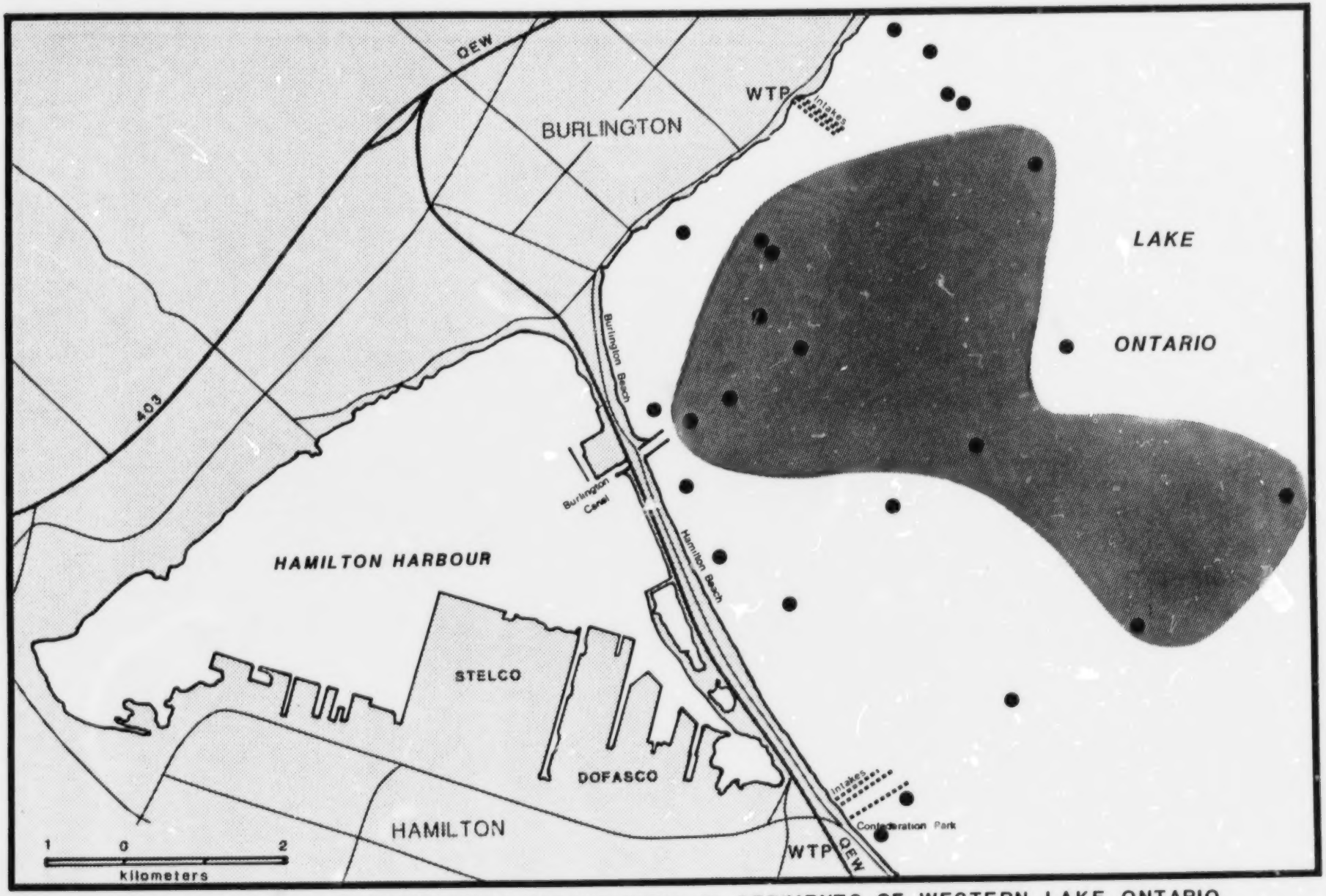

FIGURE 5.20 : OCCURENCE OF LIMNODRILUS HOFFMEISTERI IN SEDIMENTS OF WESTERN LAKE ONTARIO, AUGUST 1983

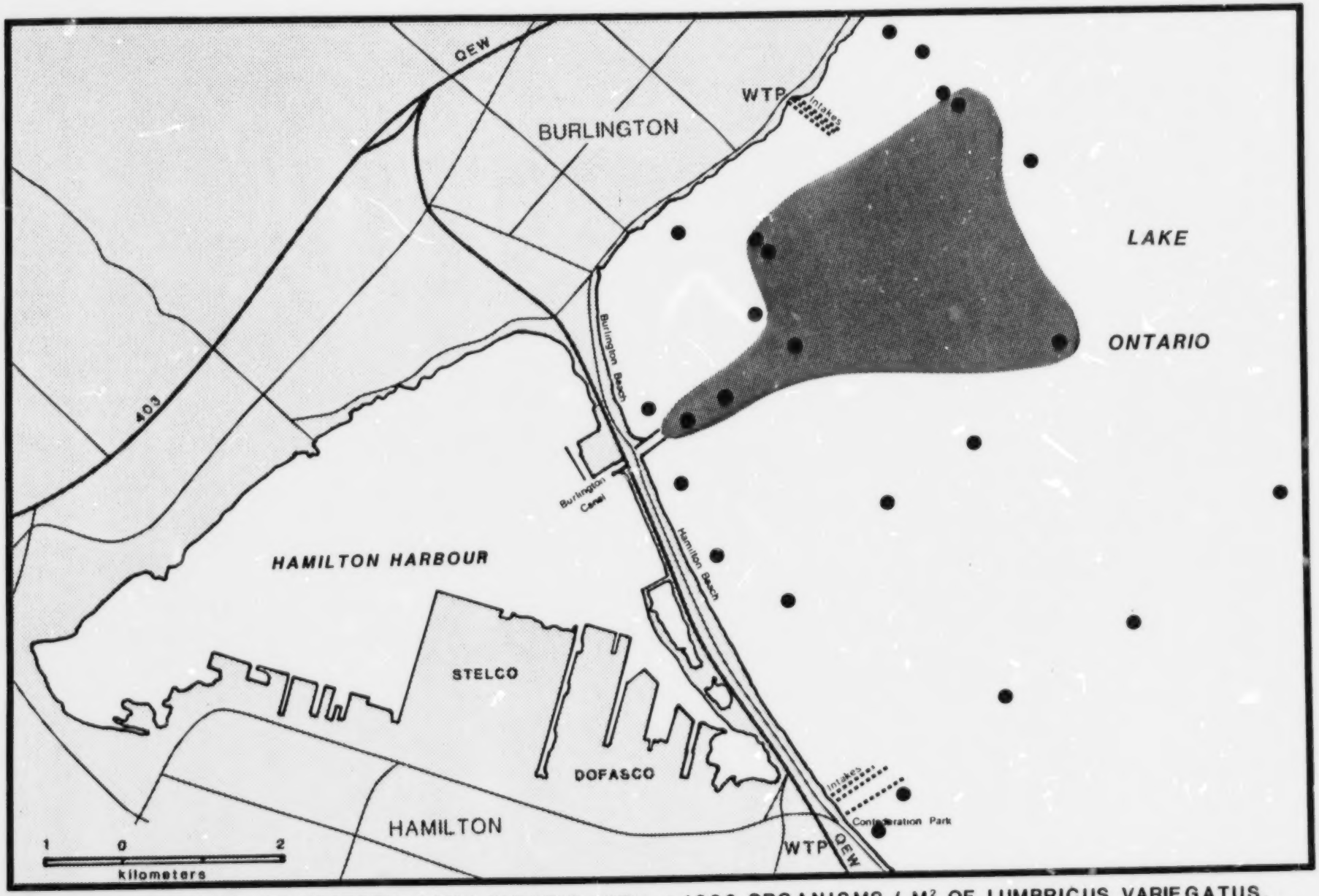

FIGURE 5.21 : AREA OF WESTERN LAKE ONTARIO WITH >1000 ORGANISMS / M^2 OF LUMBRICUS VARIEGATUS, AUGUST 1983

6.0 THE DISTRIBUTION OF POLYAROMATIC HYDROCARBONS IN THE SEDIMENTS OUTSIDE HAMILTON HARBOUR

6.1 INTRODUCTION

The Great Lakes Section of the Water Resources Branch, Ministry of the Environment, has been investigating the effects of industrial and municipal discharges on Hamilton Harbour and on the western end of Lake Ontario for several years. A study in 1982 showed that the effluents from Stelco and Dofasco contain numerous polyaromatic hydrocarbons (PAHs). These include several EPA priority pollutants, some alkylated and low molecular weight PAHs, such as indene and quinoline. The discharge from the Hamilton Sewage Treatment Plant, on the other hand, contains almost no PAHs above the detection limits. (MOE, Great Lakes Section, Water Resources Branch, 1985).

This study was undertaken to determine whether PAHs from industrial discharges were exported from the harbour to the lake, what the concentrations were in the surface sediments and in cores, and what factors govern the distribution of compounds in the sediments. A simultaneous study, using the same sediment samples, was done on trace metal concentrations.

6.2 METHODS

The sediment samples were collected between August 22 and 24, 1983, by staff from the National Water Research Institute in Burlington, under the direction of Dr. K.R. Lum. At Stations 384 and 385 (Figure 6.1a) in Hamilton Harbour, 600 litres of water from depths of 2 and 17 metres were centrifuged aboard the survey vessel to collect the suspended particulate fraction. The samples were preserved in aluminum foil and frozen until use. At Stations 360 to 383, inclusive, 3 Shipek samples were collected. The sediments were placed in glass jars with aluminum foil lining the lids and frozen until analyzed. At Stations 372 and 378, 4 benthos and 4 box cores samples were collected. Benthos cores were extruded on board the vessel, sectioned in 1 or 2 cm layers and stored as above.

The samples were sent to Zenon Environmental Inc. for analysis. The samples were homogenized, extracted for one hour with a one-to-one acetone-hexane mixture, centrifuged, passed through a Na_2SO_4 column, taken to dryness in a rotary evaporator followed by a nitrogen stream, and then made up to 1.5 mL with dichloromethane. A 500 uL aliquot was then cleaned up by passage through an ultra-styragel column, using dichloromethane as the mobile phase. The extract was then again taken to near dryness and made up to 5 mL in a one-to-one acetonitrile-water solution. A 50 uL aliquot was then put through an ODS reverse phase column on a high pressure liquid chromatography unit using an ultra-violet detector at 254 nm. The area under the sample peak was compared to the area of a standard and the concentration expressed in ng/g of dry sample. A method blank did not show anything at the detection limit of 10 ng/g.

Quantification was done for 10 compounds (see Table 6-1) identified in the previous study on steel mill effluents. Significant amounts of other compounds were also found in the sediments, but not quantified. These are believed to be chrysene and benzo(a)anthracene. Duplicate samples were run for Stations 375 and 378. Agreement was better at 378 where the 6 identified compounds range from 10 to 250 ng/g and the ratio of concentrations between the two samples from 1.0 to 1.25, than at 375 where only 4 compounds were identified at concentrations from <10 to 40 and the ratios range from 0 to 2.0. (Zenon 1984)

In 1982, several laboratories analyzed for PAHs, a series of steel mill effluents from Stelco and Dofasco in an interlaboratory comparison of analytical methods. The unpublished results for the one sample analyzed by both Zenon and the MOE laboratory at Rexdale indicated that the methods used by the two laboratories gave quite comparable results.

Other sediment variables, including heavy metals and weight lost on drying were determined by Barringer-Magenta. The methodology is described in Barringer, 1984.

The particle size distributions of the surface sediments were determined by the MOE Rexdale laboratory, using a Leeds and Northrup Microtrac analyzer. This instrument calculates the volumes and numbers of the particles from low angle light scattering. The particle diameters are then calculated from the volumes, assuming a sphere. The size range covered by the machine is 0.17 to 1000 um.

Most statistical analyses were done on an IBM-PC using the Microstat statistics software package (Ecosoft Inc., Release 4.1).

Samples of dried sediment from the core at Station 372 were sent to Department of Biology, McGill University for determination of ^{210}Pb activity. The age of the sediment was calculated by H.K.T. Wong of the Aquatic Ecology Section, National Water Research Institute in Burlington, Ontario.

6.3 RESULTS AND DISCUSSION

Table 6.1 gives the sample statistics for the 10 identified compounds for surface sediment samples at stations outside the harbour and for suspended particulates at 384 and 385 inside the harbour. Figure 6.1a gives the distribution of total PAH concentrations (equal to the sum of the concentrations of the 10 compounds). Figure 6.1b gives the distribution of total PAH, corrected for clay content. The clay content was calculated from the size distribution as the volume percent of particles $\leq$ 2.63 um in diameter. The median concentration of total PAH in the sediment samples collected is 750 ng/g (dry weight), the first quartile is 110 and the third is 1,330 and the range is from 30 to 4,610 (16 samples).

The distribution of PAHs and trace metals in the sediments depends upon the distribution of fine grained (clay) sediments, as the pollutants are associated with the clay size fraction of the suspended material. Since the nearshore zone is an area of active sediment resuspension by wave action, the fine particles will be sorted and deposited in the offshore area. This is consistent with the increase in PAH concentrations towards the offshore depicted in Figure 6.1a.

In order to allow for this size-sorting effect, the PAH concentrations were divided by the clay fraction (clay-collected concentration; Forstner and Wittman, 1983). The resulting distributions (Figure 6.1b) shows a band of higher concentrations along the northeast shore as well as an area (station 372) directly offshore from the Burlington Ship Canal that suggests some direct input from Hamilton Harbour. However, the existence of an area (station 361) of high PAH concentration in the northeast corner of the study area suggests an additional unknown source outside the study area, possibly in the Oakville area. This area of elevated PAH concentration is near the Burlington WTP intake.

6.3.1 Comparison with concentrations of PAHs found elsewhere in the Great Lakes.

Exact comparisons of total PAH concentrations at different locations is difficult since the same compounds are not present at all locations. A recent study of trace organic substances in the western basin of Lake Ontario (Onuska, Mudroch and Terry 1983) showed that the PAH concentrations in the deeper portion were about 10 ng/g (dry weight; 0-3 cm) and close to the mouth of the Niagara River, about 900. The median concentration outside Hamilton Harbour is around 600 ng/g.

However, it is possible to compare the concentration of specific compounds, bearing in mind that analytical biases among various laboratories might exist. Table 6.2 compares the concentrations of some PAHs in the five Great Lakes[1] (IJC 1984), the results of the present study and other MOE surveys of Hamilton Harbour and other nearshore areas of the lakes. The concentrations outside the harbour are comparable to the concentration found in the Great Lakes. However, the small sample sizes make it impossible to do an exact comparison. The concentrations in the harbours and near Buffalo are indicative of heavily contaminated sediments. The highest levels in Hamilton Harbour are found close to the steel company discharges, and a slight elevation is also found near the Hamilton STP (Poulton, 1986). The concentrations on the suspended particulates in the harbour (Stations 384 and 385; Table 6.1), are within the range found in the sediments. The various steel plant outfalls vary considerably in the composition of their effluents, but in the effluent from the Hamilton

sewage treatment plant, nothing was found above the detection limit of 10 ng/L.

6.3.2 Changes in concentration and age with sediment depth.

The sediments at Stations 372 down to 12 cm were analyzed for PAHs. Other variables were analyzed down to 40 cm (Barringer 1984). Figure 6.2 shows the concentrations of total PAH and copper and percent loss on drying, which is used as the indicator of sediment character as particle size data is not available. The percent loss on drying is uniform below about 20 cm and shows a peak at around 15 cm. This peak is also associated with higher concentrations of copper, which increase towards the sediment-water interface. The surface concentration is below the mean concentration - 100 to 130 ug/g - in the harbour.

This distribution suggests that the material below 20 cm probably represent undisturbed, historical sediments, that finer, more contaminated sediments were deposited in the 15 to 20 cm interval and above this the sediments have a concentration about twice the background, increasing towards the surface. The reason for the peak and subsequent decline are not known, as, according to the age of the sediments (Figure 6.3), the event occurred more than 40 years ago.

The distribution of PAHs is difficult to interpret, as there are only 5 data points. The concentration distribution parallels that of the copper, except for a decrease right at the surface.

The age of the sediments increases uniformly with depth from 3 to 12 cm suggesting a uniform depositional regime. The top two centimetres were deposited within the last 1.5 years.

---

[1] The low concentrations in Lake Michigan are found in areas where sediments are not accumulating.

Station 378 shows a more normal distribution, with percent loss on drying decreasing rapidly from the surface to about 35 to 40% at 10 cm. Trace metals such as lead and copper show a similar decrease, indicating that the more recently deposited sediments have higher concentrations of trace metals (Figure 5.15). A small maximum at around 10 cm may be the result of the same processes causing the maximum at 15 cm in core 372. Since the sedimentation rate is likely to be less at 378, the maximum has been covered by less sediment. The lead concentrations below 30 cm are close to background levels in the western basin of Lake Ontario of around 25 ug/g measured by Mudroch (1983), but the Cu concentrations are around 1/2 to 2/3 of the background (50 ug/g).

6.3.3 Export of PAHs to Lake Ontario.

At equilibrum, the mass of PAHs is predominantly in the dissolved phase (IJC 1984, Figure 3B-2). The dissolved fraction ranges from 0.7 to 0.95 when the total suspended solids concentration is 10 mg/L. Total PAH on suspended solids average around 4.4 ug/g. Assuming a suspended solids concentration of 10 mg/L, the mass of total PAH on the suspended particulate phase in a litre of harbour water is 4.4×10^{-2} ug. This represents 0.3 to 0.05 of the total concentration, or 0.15 to 0.88 ug/L. The flow out from the harbour is around 38 m^3/s or 1.20×10^{12} litres a year. Hence, the total amount of PAHs exported is from 180 to 1050 kg per year.

The atmosphere is probably the major source of PAHs to the Great Lakes (IJC 1984), forming about 90% of the load. For Lake Ontario, the estimated atmospheric loads range from 1,000 to 2,000 kg per year for each compound. For the compounds studied in this report, the fraction in the particulate phase is around 0.05. Therefore, the export of fluoranthene, the most prevalent compound in the suspended fraction, is around 600 kg per year and that of benzo(a)pyrene is 40 kg per year. Thus the export from the harbour can range from a negligible fraction to perhaps 30-40% of the atmospheric input.

6.4 SUMMARY

1. Although Hamilton Harbour contributes a minor, but probably significant amount of PAHs to Western Lake Ontario sediments, the atmosphere is the major PAH source. This is based on estimates of relative PAH loadings, as well as the observed distribution of PAHs in the sediments. An area of elevated PAH concentration in the northeast corner of the study area may indicate an unknown source outside the study area.

2. The PAHs are associated with the clay size fraction of the sediments. In the near-shore zone the sediments are re-suspended and the finer particles are carried by the current and deposited offshore. The depositional zones depend also on the bottom topography. As a result, the PAH concentration generally increases with depth and distance from shore.

3. The water intakes for both Burlington and Hamilton are close to sediments with elevated levels of PAHs. The effects on the water supplies are not known.

6.5 REFERENCES

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TABLE 6.1

Distribution of polyaromatic hydrocarbons in sediments outside Hamilton Harbour and on suspended particulates inside the Harbour

COMPOUND	STATION[1] 361	363	364	366	368	371	372	375	378	380	381	382	383	384 2m	385 2m	385 17m
TOTAL (ng/g)[2]	4610	1330	930	590	750	470	840[4]	65[5]	30[5]	590	110	520	980	3340	4350	5530
Naphthalene (%)[3]	21.7	24.8	30.1	20.3	5.3	23.4	14.9	----	----	----	----	----	----	----	----	16.6
Acenaphthylene	---[6]	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Acenapthene	22.6	18.8	----	27.1	25.3	----	----	----	----	13.6	----	30.8	35.7	----	----	----
Phenanthrene	10.6	11.3	16.1	6.8	8.0	10.6	16.1	23.1	16.9	15.3	9.1	13.5	12.2	14.4	14.3	9.8
Anthracene	0.7	0.8	2.2	----	----	----	1.8	----	2.3	1.7	----	1.9	1.0	----	----	----
Fluoranthene	25.8	30.1	44.1	25.4	22.7	29.8	37.5	46.2	50.6	39.0	45.5	44.2	31.6	56.9	62.8	39.4
Pyrene	12.6	9.0	4.3	17.0	9.3	21.3	21.4	23.1	16.7	13.6	36.4	1.9	12.2	18.0	14.9	24.8
Benzo(b)fluoranthene	2.6	3.8	2.2	3.4	2.7	6.4	6.0	7.7	6.7	5.1	9.1	3.9	2.0	6.0	3.9	7.2
Benzo(a)pyrene	0.9	1.5	1.1	----	2.7	8.5	2.4	----	6.7	11.9	----	3.9	3.1	4.8	4.1	5.8
Fluorene	2.6	----	----	----	----	----	----	----	----	----	----	----	2.0	----	----	----

Notes:
1. 384 and 385 are inside the harbour. 2 m and 17 m are the depths at which the samples were collected. Stations 376 and 377. All concentrations were below the detection limit (10 ng/g).
2. Dry weight basis.
3. As % of total.
4. Average of 0-1 and 1-2 cm layers.
5. Average of duplicate samples.
6. The symbol ---- indicates that compound not detected (detection limit 10 ng/g).

TABLE 6.2
Ranges of concentrations (ng/g) of selected PAHs in Great Lakes Sediments

COMPOUND	SUPERIOR[1]	MICHIGAN[1]	HURON[1]	ERIE[1]	ONTARIO[1]	TORONTO[2] HARBOUR	HAMILTON[3] HARBOUR	NEAR[4] BUFFALO	PRESENT STUDY
Phenanthrene	34	6-126.8	11-272	18-431	10-205	2718-7000		419-10198	<10-490
Fluoranthene	88	9-1664	33-487	65-285	210-1000	3531-12500	1900-43400	3415-15032	<10-1190
Pyrene	53	8-1430	36-256	57-287	56-1182	2875-3750		910-17027	<10-580
Benzo(a)pyrene	28	4-944	23-294	56-173	76-306	1000-3025	1800-11100	704-3072	<10-70
n =	1	10	3	4	5	2	6	4	15

1 IJC, 1984
2 Unpublished MOE data
3 MOE, 1983, on a wet weight basis
4 Black, Great Lakes Section, WRB, 1985

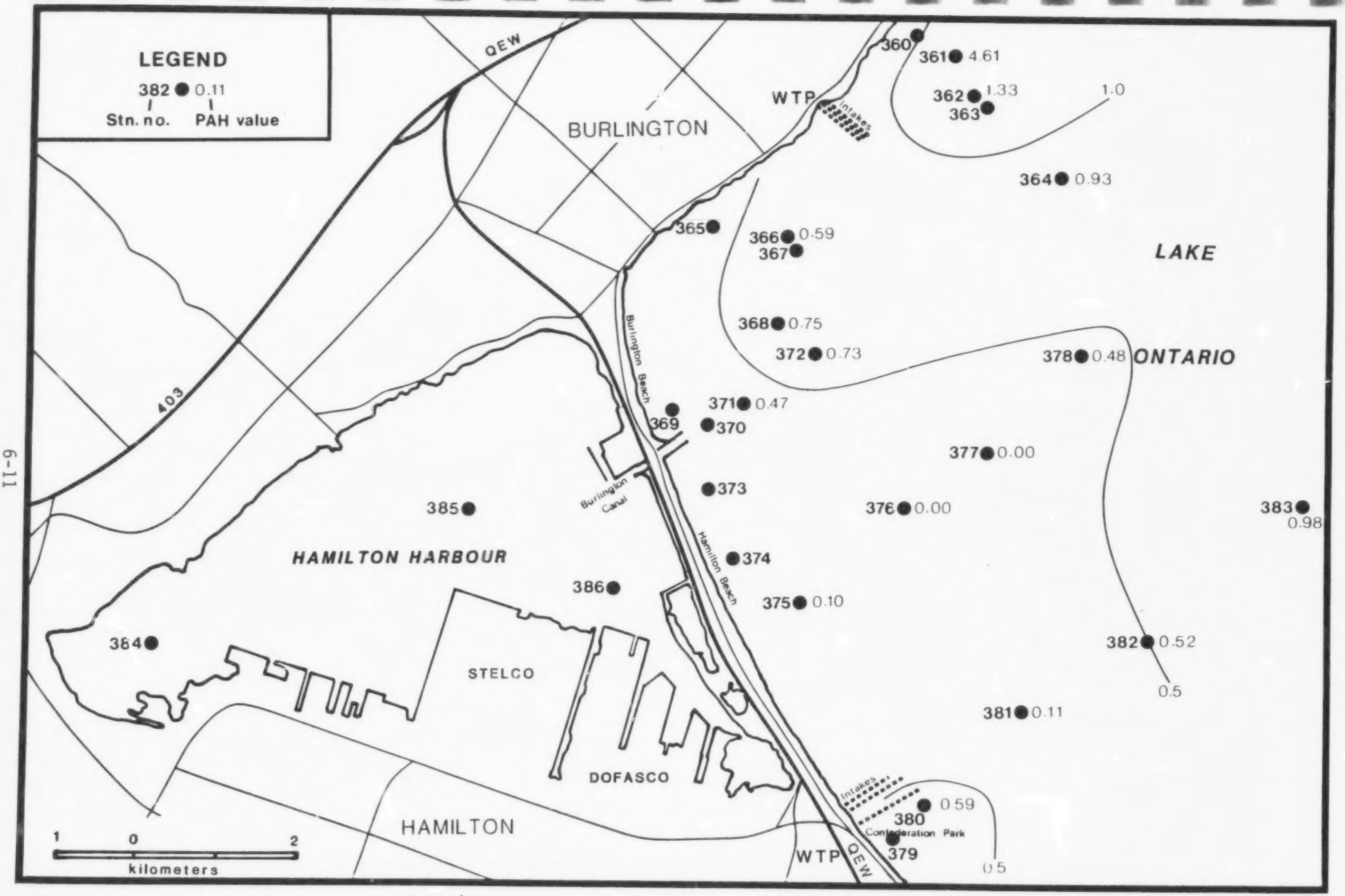


FIGURE 6.1a: TOTAL PAHS (µg/g dry sediment)

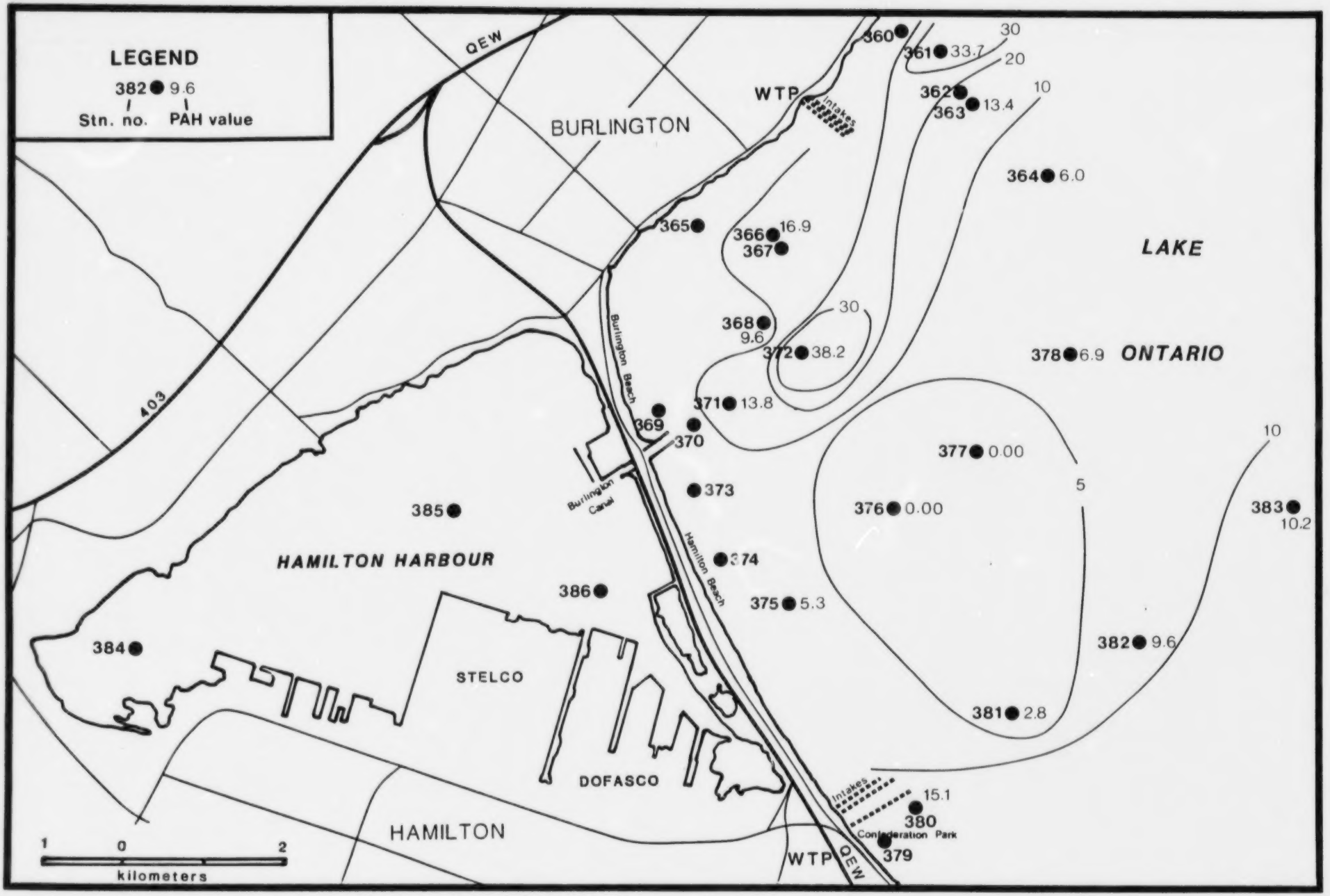


FIGURE 6.1b: TOTAL PAHS, CORRECTED FOR CLAY CONTENT (µg/g dry sediment)

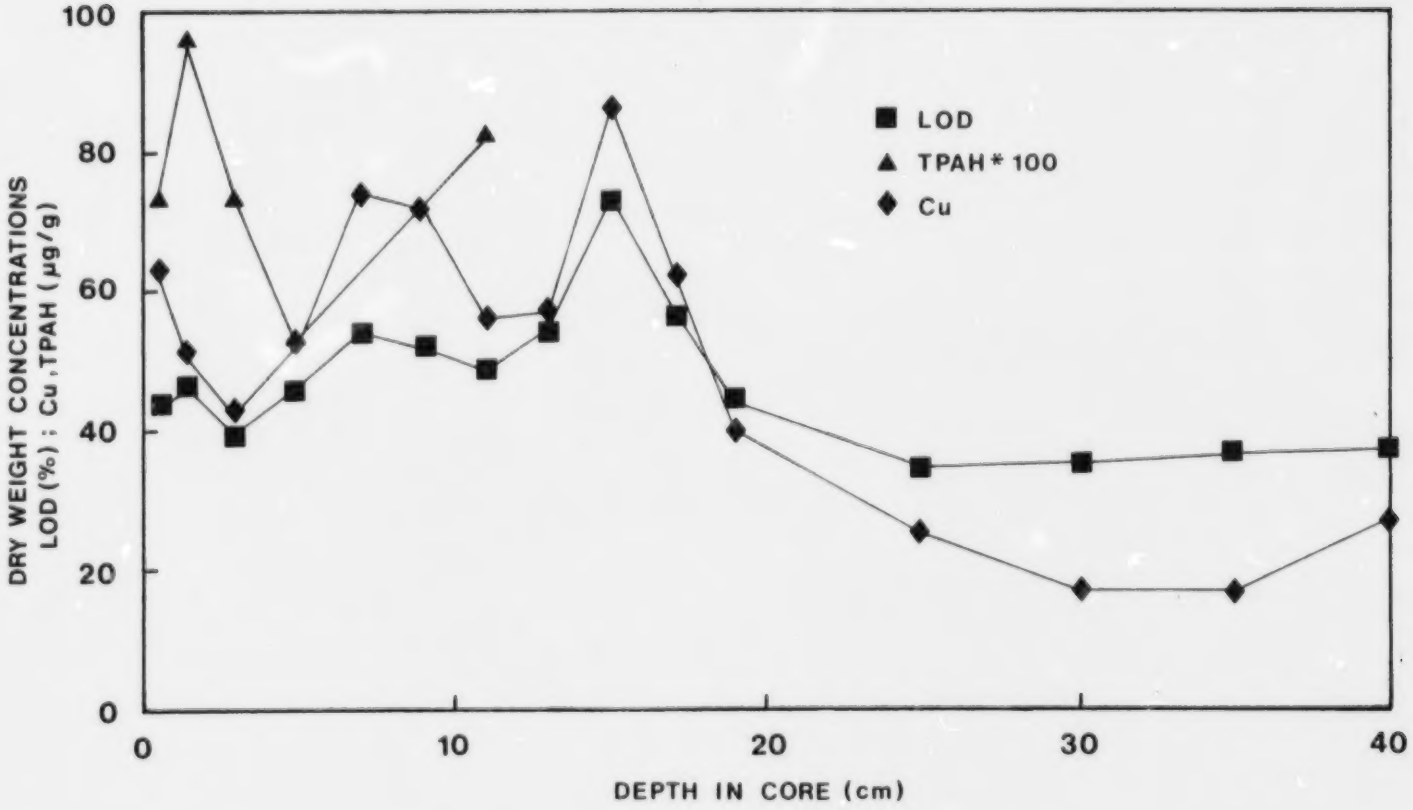


FIGURE 6.2: Cu, LOD AND TPAH CONCENTRATIONS IN CORE #372

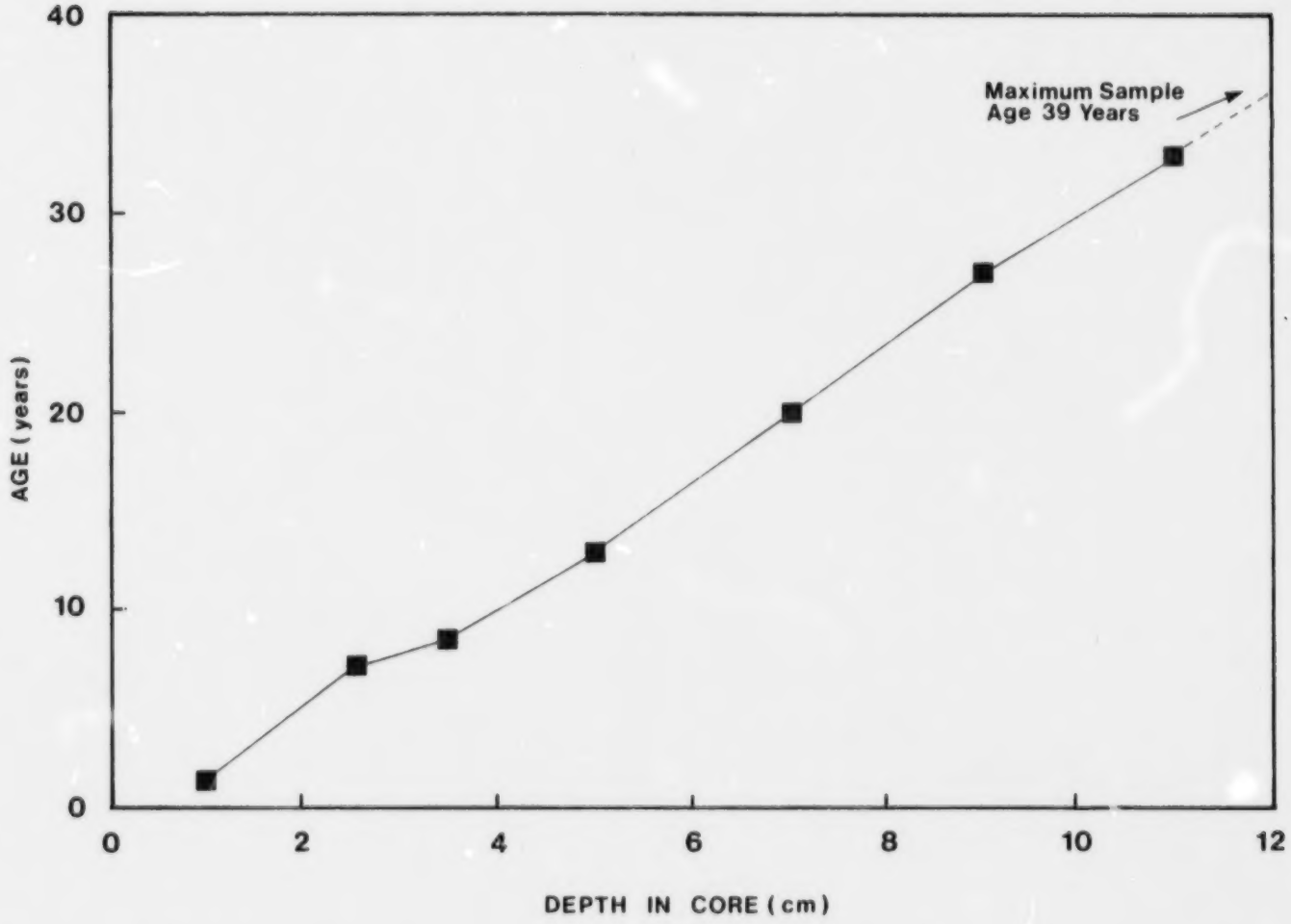


FIGURE 6.3: AGE OF SEDIMENTS IN CORE #372 BY ^{210}Pb DATING METHOD

7.0 WATER TREATMENT PLANT INTAKES

Samples of raw water were taken directly from Hamilton and Burlington Water Treatment Plant intake pipes weekly from May 20 to September 1, 1982 and analyzed for the same parameters determined in the canal and plume chemistry surveys. Samples were also taken on the survey dates in May, June and August, while the survey was in progress. The purpose of these samples was to determine whether or not impingement of the water supplies by the Hamilton Harbour plume was occurring.

Averages and standard deviations of the data obtained are given in Table 7.1. Initially, these were compared to the results of background samples obtained at 6-m water depth, using a t-test. The 6 m water depth was chosen as being similar to the depths from which the intakes draw. Background sampling locations were selected based on criteria outlined in section 4.2. Only copper at Burlington and manganese at Hamilton showed significant differences at $P \leq 0.05$. Copper was observed to be consistently higher in the Burlington intake, than in either the Hamilton intake or any of the plume samples. The source of this contamination is presently not identified. Manganese concentrations were considerably lower than the Ontario drinking water objectives. The contribution of this element was thus not investigated further.

Despite a lack of significant differences, the data in Table 7.1 indicate concentrations somewhat higher than background for several parameters, notably nutrients and turbidity in the intakes. These are accompanied by high standard deviations, sometimes higher than the mean. For further comparison, results greater than (mean + 2 standard deviations) of the 6-m background value were presented in Table 7.2. Chloride and suspended solids were not included because they did not exceed this limit. These limits were chosen as suggesting a possible effect from the harbour, or other sources.

Recalling the discussion of Section 4.5, it was suggested that ammonia was a sensitive indicator of the presence of harbour water. Ammonia was present at concentrations significantly higher than lake background values on 6 of 21 survey dates at the Hamilton WTP, and on 4 of 23 survey dates at the Burlington WTP. One of these four dates at Burlington was a plume survey date (June 29). The plume tracking results for June 29 (Figures 4.2a-4.2d) showed a large chlorophyll plume directed towards the Burlington intake from the canal. The conductivity plume was not as large but followed a similar direction. Unfortunately, no chemical samples were taken from the lake boat when it was in the more northerly portion of the chlorophyll plume; Figure 4.18 shows total phosphorus results and sample locations for chemical analysis. Surface ammonia results at points D and F were 0.94 and 0.64 mg/L, respectively, indicating strong contamination; at the 6-m depth the concentrations were 0.102 and 0.034 mg/L, respectively. The results are highly suggestive of the ammonia plume reaching the intake, presumably with depth mixing occurring as the water approached the shore.

The situation for May 20 and 21 at Hamilton, exhibited contrasting features. On May 20, the conductivity and chlorophyll plume extended about 1 km east and south of the canal; a sample taken 1 km south of the canal piers indicated 0.012 mg/L NH_3-N, less than one-sixth the concentration observed at the Hamilton intake. On May 21, the plume was directed largely northward extending about 2 km from the canal. To the east and south, plume conditions existed for less than 1 km from the canal. However, the chemical sample taken 2.2 km south of the canal showed 0.122 mg/L NH_3-N, similar in concentration to that observed at the water intakes, about 3 km further south. The results of May 20 suggest a sinking plume or an ammonia source other than the harbour to be affecting the Hamilton intakes; on May 21, the situation is less certain. These data were obtained under conditions of rainfall and high winds; in fact the May 21 survey was aborted due to rough water conditions. Rainfall was 9.6 and 5.6 mm on May 19 and 20, respectively. Average wind was 18.9 km/h from SW on May 19; 16.8 km/h from SW, gradually changing to NW then NE on May 20; and 24.5

km/h from ENE on May 21, when the survey was aborted. These high northeasterly winds continued on May 22, with an average of 26.3 km/h from NE and 6.4 mm precipitation, conditions which prevented a plume survey but did allow a sample to be taken at the Hamilton water treatment plant, indicating elevated NH_3 (0.220 mg/L) and TKN (0.60 mg/L) readings. Clearly, non-point source runoff and transport from other lake areas is a potential source of ammonia under these conditions.

The results for July 29 clearly indicate the effect of storm-induced sediment resuspension or runoff. After a 16-mm rainfall on July 28 and average 16.7 km/h winds from the north, turbidity was above 8 FTU at both Hamilton and Burlington intakes. It should be recalled (Section 4.5) that turbidity was a poor indicator of the harbour plume. Nitrate-N and FRP were also elevated at Hamilton in this date; there was no sample for TKN or total P.

Considering these results, other data in Table 7.2 for elevated nutrient levels on weekly samples (Hamilton: June 4, 11, July 2; Burlington: June 22, July 14, 20) indicate possible plume impingement on the intakes. In particular, June 4 featured strong (21.4 km/h) northeast winds, a situation not unlike that of May 20-22. Most of July 20 had NE to ENE winds (10-32 km/h).

Several dates also indicated elevated heavy metal concentration without elevated nutrient concentrations, for example May 24 and July 2 at Burlington. The former was a survey date, in which iron was found in all samples taken close to shore, as high as 0.472 mg/L at a point 1.5 km north of the canal and 0.3 km from shore. This sample had a turbidity of 16.2 FTU and suspended solids of 16.3 mg/L. Most other nearshore samples had high turbidity and suspended solids, indicating resuspension as the source. Unfortunately, no turbidity or suspended solids data were obtained for May 24 at Burlington.

Intake nutrient results plus plume survey data support impingement of the harbour plume at the Burlington intake at least once (June 29). Plume survey data for October 23 (Section 4.5) suggests possible impingment at the Hamilton intake, but no intake samples were taken. Elevated nutrient concentrations on several other dates may be due to either plume impingement, or external sources such as runoff or transport from other areas, while occasional elevations of heavy metal concentration are most likely from sources other than the harbour.

7.1 Drinking Water Monitoring

Samples of raw and finished water at Hamilton and Burlington Water Treatment Plants (WTP) from 1982 to 1985 have provided additional data for conventional and priority pollutants. As part of ongoing in-plant monitoring by the Ministry of the Environment, conventional water quality parameters and a large number of trace contaminants were analyzed in raw water and various stages in the finished distribution system. Conventional parameters are monitored on a monthly basis, while organic constituents are documented less frequently. During 1984, organics were measured on 8 occasions at the Burlington WTP. Haloform compounds were monitored between 5 and 10 times annually from 1982 to 1984 at the Hamilton WTP.

In addition, non-routine assessment as part of the Drinking Water Surveillance Program (DWSP) at Hamilton WTP was conducted in early 1986 for a complete range of parameters including nutrients, water chemistry, trace metals, bacteria and trace organics.

7.1.1 Conventional Parameter Monitoring

Results for conventional parameters show sporadic elevations which are difficult to correlate with Harbour conditions. Meteorological data provide some insight of possible plume movement; however, actual tracking of the plume with corresponding intake samples is necessary to identify impingement.

Conventional parameters measured in raw water at Hamilton and Burlington Water Treatment Plants show little variability with time. Occasional exceptions to this are colour, turbidity, phosphorus, ammonia and heavy metals (copper, iron, manganese and zinc); however, these have not been shown to be good indicators of plume presence.

Elevated levels of iron, phosphorus, turbidity and colour on February 28, 1984 in the Burlington WTP raw water correspond to extremely high northeast winds averaging 46.8 km/hr for that day. These elevations are likely the result of sediment resuspension and not attributed to a harbour plume. Conversely, elevated iron and turbidity at Burlington on December 19, 1984 may have been due to winds predominantly from the west and south at 10.8 km/hr facilitating plume movement out of the harbour and northwards to the Burlington intake.

7.1.2 Organic Compounds Detected in Raw and Finished Water

To address concerns over the presence of trace organic contaminants, the Ministry of the Environment subjected raw and finished water at the Hamilton WTP to GC/MS analysis for extractable organics including chlorinated aromatics, pesticides, PAH's and phenols once in 1982 and three times in 1983.

With the exception of alpha-hexachlorocychlohexane (α-BHC) detected at 4 ppb in Hamilton raw water (June, 1982), no other extractable organics were detected in raw waters. Dibutylphthalate and Bis (2-eth.hex.) Phthalate were measured in treated water on one occasion at 1 and 2 ppb, respectively. These compounds generally occur as a result of contact with plastic pipes or plumbing within the distribution system and are not likely a result of contaminated harbour water. As well, α-BHC has been shown to be generally present at low levels in Lake Ontario Water (Poulton 1986); therefore, its presence is not unexpected.

Compounds such as ammonia, phenols and PAH's which are associated with steel-making activities would be expected to occur in raw water, albeit at trace concentrations, if Hamilton Harbour plume migration impinged on drinking water intakes in western Lake Ontario. Unfiltered, reactive phenolics were tentatively identified in Hamilton treated

drinking water but at concentrations (0.2-0.4 ppb) which are not reliable and may not be significantly different from zero.

Ammonia levels in raw and treated water are typically reported at 0.1 ppm; however, an analytical footnote indicates that the actual value may not be different from zero and is a likely a background concentration. One exception to this is ammonia measured at 0.152 ppm in Hamilton raw water February 2, 1986, indicating possible impingement.

Trihalomethanes and other volatile halogenated organics detected in raw and finished water at both Hamilton and Burlington WTP's are listed in Table 7.3. These compounds occurred above detection limits in 0-20% of raw water samples and with a frequency of 40-100% in finished water samples. Occasionally, trihalomethane levels in raw water exceeded levels in finished water; however, this occurred very infrequently with most (94%) raw water samples below detection limits. It is acknowledged that haloforms occur in drinking water supplies (MOE 1984) and that chlorination results in elevated concentrations in finished water.

The increased incidence of trihalomethanes in finished water may be attributed to the chlorination of naturally occurring humic and fulvic acids is known to be a principle cause in the production of trihalomethanes. Other possible, but less important factors which contribute to organic and inorganic compounds in finished vs. raw water may be the introduction of trace levels of contaminants through chemicals added in the treatment process and through contact with materials in the distribution system. Changes in physical/chemical conditions brought on by treatment additives (e.g. alum, ferric chloride - the latter not used at Hamilton WTP) may result in the reformation and redistribution of compounds subsequently detected in finished water. The presence of phthalates may be explained by these mechanisms; however, this is not confirmed.

7.2 REFERENCES

Lederer, W.H. 1985. Regulatory Chemicals of Health and Environmental Concern. Macmillan of Canada. Toronto. 304 pp.

Ministry of the Environment 1984. Water Management: Goals, Policies, Objectives and Implementation Procedures of the Ministry of the Environment. 70 pp.

Poulton, D.J. 1986. Hamilton Harbour Trace Contaminants 1982-83. Loadings to, and Concentrations in the Harbour. Water Resources Branch, Ontario Ministry of the Environment.

TABLE 7.1

Average Water Chemistry Results
for Water Supply Intakes 1982 (mg/L)

Parameter	Hamilton			Burlington			Drinking Water Objective
	N	Mean	SD	N	Mean	SD	
NH_3-N	21	0.046	0.047	23	0.060	0.105	-
TKN	20	0.411	0.205	22	0.571	1.10	0.15*
(NO_2+NO_3)-N	21	0.346	0.076	23	0.355	0.133	10.0
Total P	20	0.026	0.029	22	0.019	0.009	-
FRP	20	0.006	0.006	22	0.005	0.004	-
Cl	20	28.0	1.2	22	27.8	1.0	250.0
Turbidity (FTU)	20	1.68	1.62	22	1.76	1.58	-
Susp. Solids	20	1.83	0.92	22	1.69	0.74	-
Cu	23	0.007	0.006	24	0.019	0.009	1.0
Fe	23	0.045	0.046	24	0.052	0.055	0.3
Mn	23	0.005	0.002	24	0.007	0.011	0.05
Zn	23	0.004	0.004	24	0.004	0.004	5.0

Note* Organic N (= total Kjeldahl N - NH_3-N)

TABLE 7.2

Water Works Intake Data for Results
Greater Than (Mean + 2 S.D.) At Background
May 20 - Sept. 1, 1982

Date	NH_3-N	TKN	(NO_2+NO_3)-N	Total P	FRP	Fe	Mn	Zn	Cu	Turbidity (FTU)
(a) Hamilton										
May 20	.076	.42	*	*	*	*	*	*	*	*
May 21	.120	.43	*	*	*	*	*	*	*	*
May 22	.220	.60	*	*	*	*	.012	*	*	*
June 4	.082	.41	*	*	*	*	*	*	*	*
June 11	.060	*	*	.028	.007	*	*	*	.028	*
July 2	.074	1.23	*	.150	.029	*	*	*	*	*
July 29	*	-	.570	-	.018	*	*	*	*	8.3
August 6		*	*	*	*	*	*	.007	.014	*
*										
(b) Burlington										
May 24	*	*	*	*	*	.227	.014	*	+	*
June 22	.116	*	*	*	*	*	*	*	+	*
June 29	.072	.56	*	*	*	*	*	*	+	*
July 2	*	*	*	*	*	.220	.056	.019	+	*
July 14	.530	-	.915	.053	.018	.053	*	.012	+	*
July 20	.076	*	*	*	*	*	*	*	+	*
July 29	*	*	*	*	*	*	*	*	+	8.6

Note: All results in mg/L
* Result less than (mean + 2 S.D.) of data obtained at 6 m depth of background location (Table 4.5)
+ Average copper result at Burlington = .019 mg/L, S.D. = .009 mg/L, see text.

TABLE 7.3

TRIHALOMETHANES/VOLATILES DETECTED IN RAW AND FINISHED WATER AT HAMILTON AND BURLINGTON WATER TREATMENT PLANTS

Plant	Year	Compound	Treated	Samples	Detected	Range (ug/l)
Burlington	1984	Bromodichloromethane	Treated	10	9	0 - 9
			Raw	10	0	-
		Chlorodibromomethane	Treated	10	4	0 - 4
			Raw	10	0	-
		Chloroform	Treated	10	8	0 - 14
			Raw	10	0	-
Hamilton	1984	Bromodichloromethane	Treated	10	9	5 - 14
			Raw	10	1	18
		Chlorodibromomethane	Treated	10	9	7 - 2
			Raw	10	1	8.0
		Chloroform	Treated	10	10	4 - 370
			Raw	10	1	31
	1982	Tetrachloroethylene	Treated	10	1	5
			Raw	10	0	-
	1983	Bromodichloromethane	Treated	8	8	4 - 9
		Chlorodibromomethane	Treated	8	7	3 - 5
		Chloroform	Treated	8	8	8 - 16
		Dichloromethane	Treated	8	1	20
	1984	Bromodichloromethane	Treated	5	5	6 - 11
			Raw	5	1	11
		Chlorodibromomethane	Treated	5	3	5 - 8
			Raw	-	-	-
		Chloroform	Treated	5	5	4 - 13
			Raw	5	1	15
	1986	Bromodichloromethane	Treated	1	1	8
			Raw	1	0	0
		Chlorodibromomethane	Treated	1	1	11
			Raw	1	0	0
		Chloroform	Treated	1	1	9
			Raw	1	0	0

NOTE: The Ontario drinking water objective for total trihalomethanes is 350 ug/L.

8.0 APPENDIX

COASTAL DYNAMICS OF WESTERN LAKE ONTARIO 1982-1983

Detailed results of the data analysis were included in this appendix for reference and/or interpretation, now or at a later date.

Frequency tables of current speed and direction are presented in Tables 1.01 to 1.48. Figures 1.01 to 1.48 illustrate the Current Rose Histograms, while Figures 2.01 to 2.48 show the variations of water temperature, current direction and speed with time. Selected progressive vector plots are presented in Figures 3.01 to 3.12. Tables 2.01 to 2.04 show the frequency of occurrence of water temperature, while Tables 3.01 to 3.04 illustrate the daily current events during the period of plume trackings. Figures 4.01 to 4.5 show conductivity and chlorophyll plumes obtained on data other than those discussed in Section 4.4.

One example of each figure and table is included. The complete Appendix is published under separate cover and is available upon request from the Great Lakes Section, Water Resources Branch.

TABLE 1.01

LOCATION CODE : 1120
AREA : BURLINGTON AREA
LAKE : ONTARIO

PERIOD : MAY 82
LATITUDE : 43 18 50 N
LONGITUDE : 79 47 0 W

FREQUENCY TABLE

SPEED(CM/S)	DIRECTION IN DEGREES 337.50-22.49	22.50-67.49	67.50-112.49	112.50-157.49	157.50-202.49	202.50-247.49	247.50-292.49	292.50-337.49	ROW SUMS
1.00 -- 1.99	11.79	5.23	2.03	0.71	2.13	7.62	7.22	10.16	46.90
2.00 -- 2.99	3.86	2.03	0.97	0.91	2.74	2.95	1.47	1.63	16.57
3.00 -- 3.99	3.71	0.61	0.51	0.36	1.42	2.79	1.07	1.63	12.09
4.00 -- 4.99	0.97	0.25	0.25	0.61	2.54	2.34	0.30	0.81	8.08
5.00 -- 5.99	0.0	0.05	0.15	0.97	2.13	1.22	0.0	0.0	4.52
6.00 -- 6.99	0.0	0.0	0.0	0.81	1.37	0.56	0.0	0.0	2.74
7.00 -- 12.99	0.0	0.0	0.46	1.02	7.42	0.20	0.0	0.0	9.10
COLUMN SUMS	20.33	8.18	4.37	5.39	19.77	17.68	10.06	14.23	100.00

RESULTANT CURRENT IS 1.01 CM/S AT 202 DEG FROM NORTH
MEAN CURRENT IS 3.16 CM/S
MAXIMUM CURRENT IS 12.07 CM/S
MINIMUM CURRENT IS 1.50 CM/S

TOTAL NO. READINGS 1968
PERSISTENCE IS 0.32
READINGS TAKEN EVERY 15 MIN

METER OPERATIONS

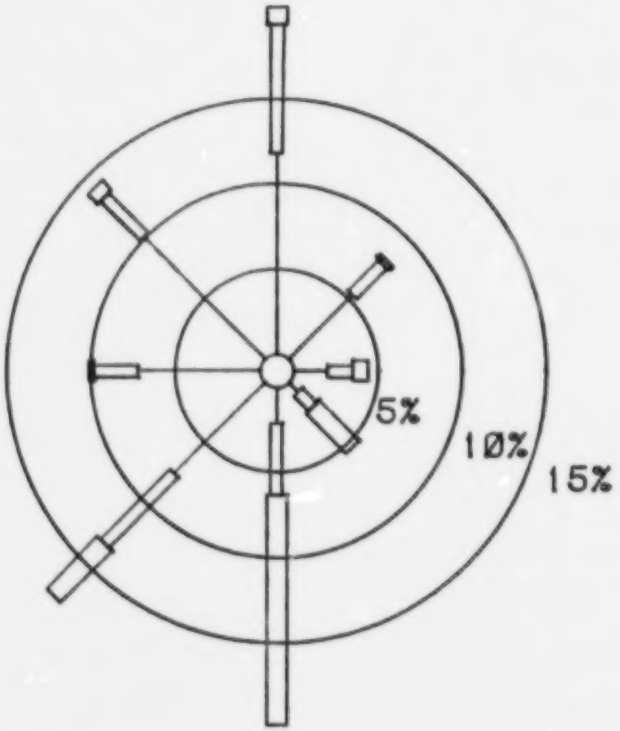
METER OPERATED AT 9.2 M FROM BOTTOM IN 12.2 M OF WATER

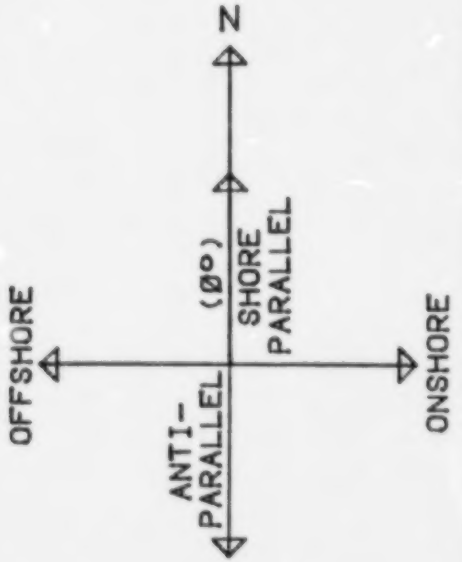
STARTED AT 0.04 HRS. ON 12 TH DAY OF 5 TH MONTH 1982
ENDED AT 23.49 HRS. ON 31 TH DAY OF 5 TH MONTH 1982

Table 2.01: Temperature Frequency, Western Lake Ontario, 1982-83
Location # 1120

Temperature Range °C	May	Jun	Jul	Aug 1-11	Aug 24-31	Sep	Oct	Nov
4.0 - 4.9		2.0	11.0		13.4			15.1
5.0 - 5.9	7.2	5.7	34.5		2.5	2.6	16.1	53.4
6.0 - 6.9	14.4	10.9	24.4		5.5	7.2	6.5	14.6
7.0 - 7.9	43.9	15.8	9.4	4.1	38.8	2.5	5.7	13.1
8.0 - 8.9	22.6	9.8	5.8	4.1	33.3	21.9	3.9	3.8
9.0 - 9.9	11.9	27.7	1.3	5.7	5.0	10.1	3.3	
10.0 - 10.9		19.9	1.9	1.6	1.5	3.7	5.5	
11.0 - 11.9		7.2	3.9	7.7		4.9	0.9	
12.0 - 12.9		1.0	2.4	8.9		5.0	0.7	
13.0 - 13.9			1.7	4.5		17.6	8.5	
14.0 - 14.9			1.9	8.5		24.5	46.8	
15.0 - 15.9			0.8	4.5			2.1	
16.0 - 16.9			0.1	3.7				
17.0 - 17.9			0.1	17.1				
18.0 - 18.9			0.3	6.1				
19.0 - 19.9			0.5	16.6				
20.0 - 20.9				6.9				
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Monthly Mean °C	7.7	8.8	7.1	15.3	7.5	11.1	11.5	5.8
Monthly Std. Dev. °C	0.9	1.8	2.7	3.9	1.4	2.8	3.7	0.9

LOCATION - 1120 (MAY 1982)





LEGEND

———	0-2	CM/S
▭	2-4	CM/S
▭	4+	CM/S

Fig. 1.01 : CURRENT ROSE HISTOGRAM: BURLINGTON AREA, LAKE ONTARIO

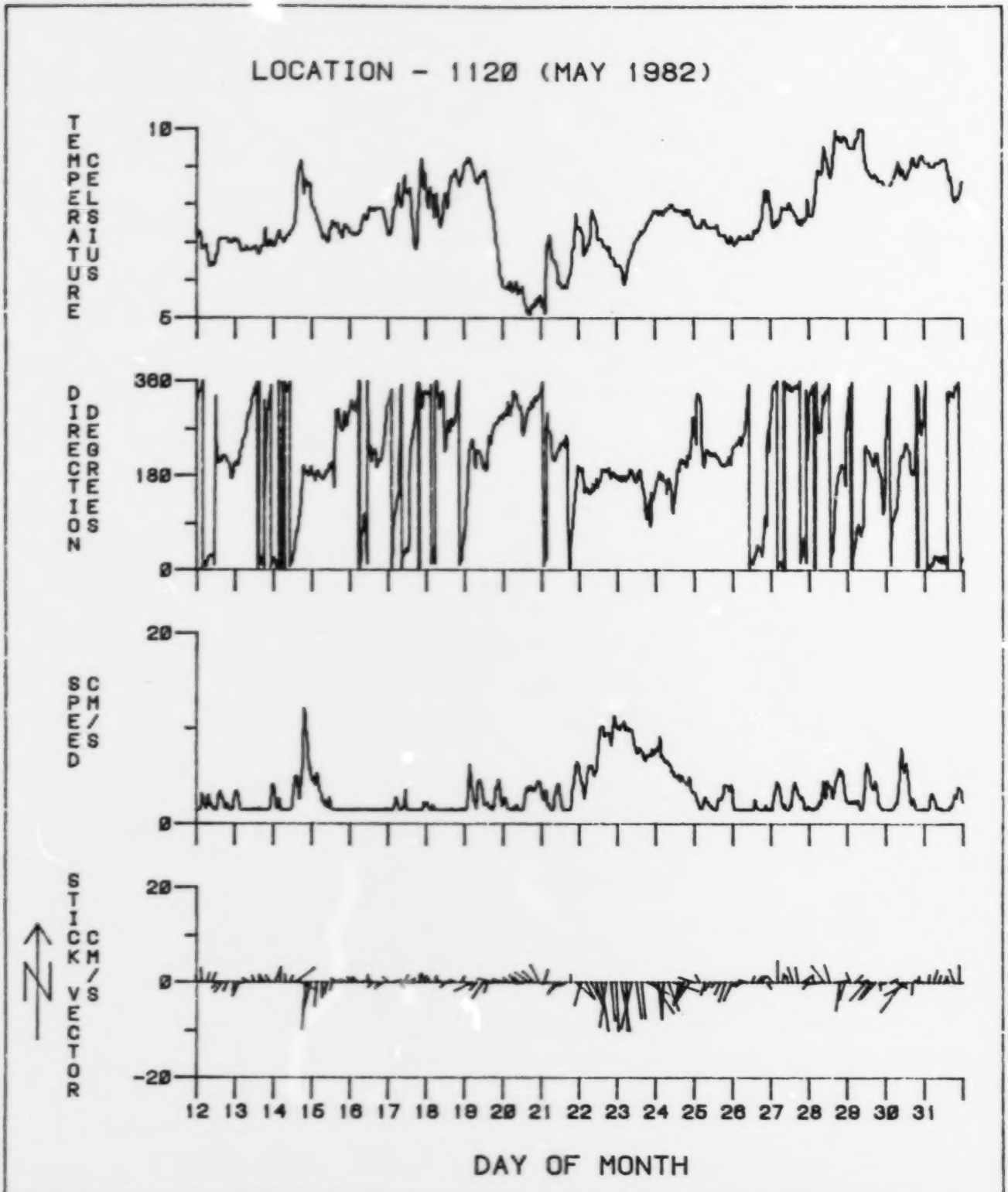


Fig.2.01 : VARIATION OF CURRENT DIRECTION, SPEED AND TEMPERATURE WITH TIME-LAKE ONTARIO - BURLINGTON AREA

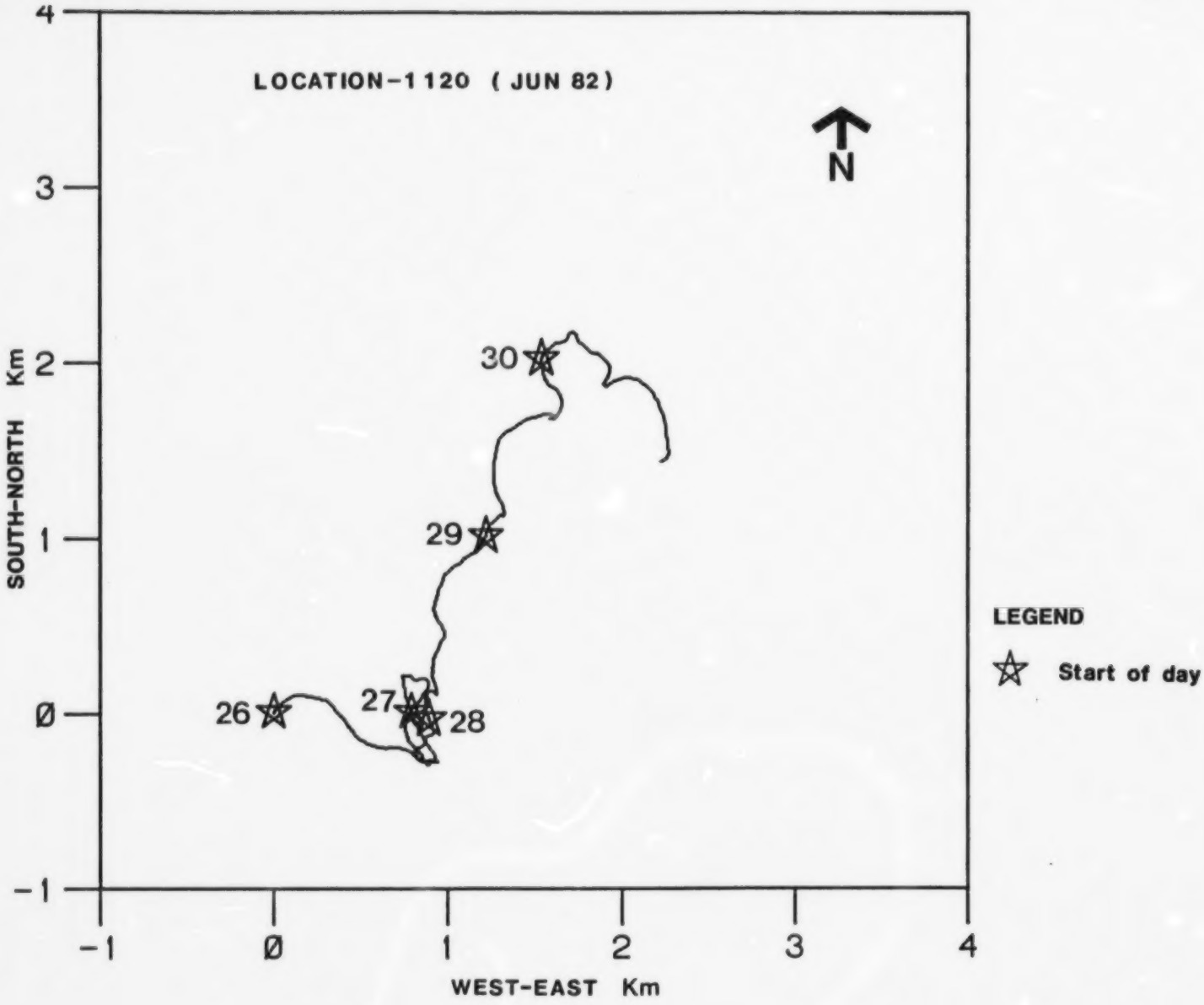


FIGURE 3.01 : PROGRESSIVE VECTOR PLOT, WESTERN LAKE ONTARIO, 1983

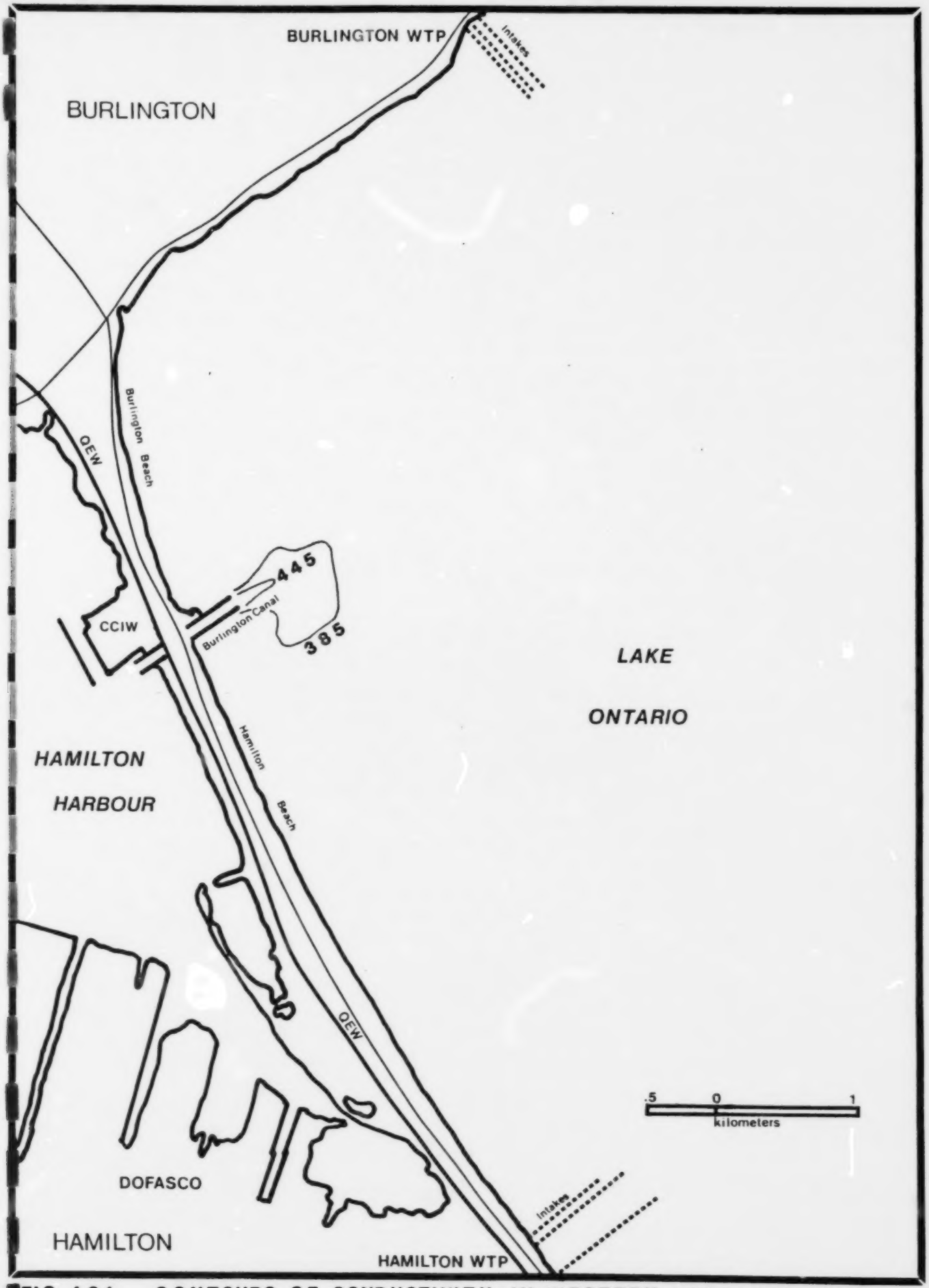


FIG. 4.01 CONTOURS OF CONDUCTIVITY IN WESTERN LAKE ONTARIO MAY 20, 1982